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A strong relationship has existed throughout the years between the International Olympic Committee and the International Paralympic Committee. Since our historic agreement in 2000, the IOC and the IPC have worked in partnership to serve athletes, promote values, fight discrimination, and increase access to sport.

A concrete example of our collaboration was the publication in 2011 of the comprehensive handbook on *The Paralympic Athlete*, edited by Professors Yves Vanlandewijck and Walter Thompson. With the contribution of a team of 17 international sports medicine physicians and scientists, this valuable guide joined the IOC Medical and Scientific Commission series, Handbooks of Sports Medicine and Science.

Today, in this handbook on *Training and Coaching the Paralympic Athlete*, our two co-editors, along with a new talented team of 10 contributing authors, provide practical information on clinical and scientific topics as well as examples of best practices.

This brand new handbook is an ideal working tool for professionals dealing with para-athletes with the objective of improving their health and welfare at all levels of competition.

Thomas Bach
IOC President
Foreword

In 2011, The Paralympic Athlete was published in the Handbook of Sports Medicine and Science series, an IOC Medical Commission Publication. It was the first time the International Olympic Committee (IOC) and the International Paralympic Committee (IPC) teamed up to focus on a comprehensive evaluation of the athlete from different perspectives, including basic science, applied science, social science, nutrition, and performance enhancement in both cold and hot environments. This book stimulated more research on Paralympic athletes, but was also utilized by the coach and the athlete as a guide to improving athletic performance. The book was a source of valuable information for coaches and athletes and was also important in the classroom where college and university courses are dedicated to the understanding of the Paralympic athlete. The book stimulated many more specific questions about coaching and training.

This new book, Training and Coaching the Paralympic Athlete, uses as a foundation the first book, but now discusses specific training and coaching techniques for the athlete. Coaches and athletes alike can use this new book to answer specific questions about training techniques for successful athletic performance and careers. Chapters not found in any other source can now be found in this one book.

Since 1989, the IPC has experienced exponential growth in the number of athletes competing against each other, with the Paralympic Gold Medal as the ultimate prize. While much has been learned about the Paralympic athlete in these past 25 years, there is still much more to be discovered. Scientists all over the world are now actively engaged in the study of Paralympic athletes and in the application of this research to training and coaching. Much of the credit for the increased interest has to be attributed to the IPC Sports Science Committee.

Prof. Dr. Yves Vanlandewijck of Katholieke Universiteit (Leuven, Belgium) and Prof. Dr. Walt Thompson of Georgia State University (Atlanta, GA, USA), both members of the IPC Sports Science Committee, have again successfully recruited the world’s best and most respected coaches and scientists to write exemplary chapters, and then amalgamated this handbook into the most comprehensive book on the subject of training and coaching the Paralympic athlete. Athletes, the IPC Governing Board, Paralympic sports, coaches, member nations, and the Paralympic Movement are indebted to all who contributed to this book.

Sir Philip Craven, MBE
IPC President
Chapter 1

Introduction to the Paralympic Movement

Walter R. Thompson
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Introduction

The Paralympic Movement, a dream and an inspiration for many, dates back to the post–World War II era of Sir Ludwig Guttmann, a Jewish physician who fled Nazi Germany for a new home and a new start in Great Britain in 1939. This neurosurgeon was now in a place where he could practice medicine freely and without religious persecution. In 1943, at the urging of the British government, Dr. Guttmann established the National Spinal Injuries Centre at Stoke Mandeville Hospital in Buckinghamshire, which opened in February 1944. In 1948, he organized the first “Stoke Mandeville Games” for people with disabilities, on the same day as the start of the London Summer Olympics. Over the next couple of decades, the Stoke Mandeville Games grew to the point where it caught the attention of the International Olympic Committee, and by 1960 was run in parallel with the Olympic Games. The first Paralympic Games took place in Rome, Italy, with 400 athletes from 23 countries competing. Today, thousands of athletes compete in the Summer Paralympic Games and the Winter Paralympic Games. Sir Ludwig died in 1980, but lived to see his dream become a reality.

This book and this chapter chronicle the foundation on which Sir Ludwig envisioned the Paralympic Movement. It is written for coaches and for athletes, the elite and the yet-to-be elite athlete who has a physical, visual, or intellectual impairment. It is a cutting-edge resource, but the authors know and understand that in this rapidly growing and expanding movement, new technology and new evidence-based classification will be introduced. These chapters offer a starting point for coaching and training the Paralympic athlete, beginning with a brief history of the movement, then more detailed training techniques, methods, systems, skills, and best practices. The chapters on technology and classification are based on current knowledge and evidence, fully understanding that these two topics specifically will be forever changing. The coach and the athlete will decide how to apply these and other chapters to their own training programs as they prepare for the greatest sporting moment of their lives.

History of the Paralympic Movement

The first Winter Paralympic Games were held in Sweden in 1976, and just like the Summer Paralympic Games have taken place every four years thereafter. Since the Summer Paralympic Games in Seoul, Korea (1988) and the Winter Paralympic Games in Albertville, France (1992), the Games have taken place in the same cities and the same venues as the Olympic Games.
The International Paralympic Committee (IPC) was formally established in Düsseldorf, Germany on September 22, 1989. More than 200 people representing 42 countries attended the event that created for the first time a global governing body for the growing Paralympic Movement. Founding members of the IPC were the Comité International des Sports des Sourds (International Committee of Sports for the Deaf, CISS), the Cerebral Palsy International Sports and Recreation Association (CP-ISRA), the International Blind Sports Federation (IBSA), the International Sports Federation for Persons with Intellectual Disability (formerly known as INAS-FMH, now INAS), the International Stoke Mandeville Games Federation (ISMGF), and the International Sports Organization of the Disabled (ISOD). The first President of the IPC was Canada’s Dr. Robert Steadward, who remained President until 2001. In that year, Sir Philip Craven of Great Britain was elected President and has served as such since that time.

Initially housed in a small office in Brugge, Belgium, in 1999 the IPC opened a headquarters in Bonn, Germany and currently employs 75 people and has over 200 members, including international federations. Today, the IPC organizes both the Summer and Winter Paralympic Games, acts as the International Federation for nine sports (alpine skiing, athletics, biathlon, cross-country skiing, ice sledge hockey, powerlifting, shooting, swimming, and wheelchair dance sport), and coordinates world championships for those sports. For a more detailed chronological summary of key events in the Paralympic Movement, see Table 1.1 and Tweedy and Howe (2011).

The top 10 greatest moments in Paralympic history

In May 2014, the IPC set out to determine what had been the most impactful events of the Paralympic Movement over the preceding 25 years. More than 500 people participated in the survey and the IPC Governing Board chose the top events (for fuller descriptions of the top picks go to http://www.paralympic.org/ipc-25-year-anniversary/top-25-moments). Thanks to Craig Spence, the IPC’s Director of Media and Communications, here are the top 10 Paralympic moments from the past quarter-century.

London 2012: Inspiring a generation, transforming a nation

The London 2012 Paralympic Games broke multiple world records and created seismic shifts in attitudes and perceptions toward people with an impairment. The Games did not just inspire a generation, but transformed a nation for ever. In September 2011, over 30,000 people attended International Paralympic Day in London’s Trafalgar Square. It was a taste of what was to come. The media interest was unprecedented, with 1 million Paralympic Games tickets sold in a matter of days, and a record 2.7 million tickets sold overall. The momentum continued in the lead-up to the Games. For the first time ever, the Games were positioned by the organizing committee, media, broadcasters, and commercial partners as a high-performance sporting event. Paralympic athletes were promoted on the strength of their abilities, as opposed to their perceived disabilities. Every worldwide Olympic partner signed up as a Paralympic sponsor, and many Paralympians starred in television and billboard campaigns. British broadcaster Channel 4 led the way with its multi-award-winning Superhumans television commercial (https://www.youtube.com/watch?v=kKTamH_xuQ), and its breathtakingly innovative Games coverage was watched by two-thirds of the UK population.

The Games attracted a record-breaking 4,236 athletes from 164 countries. They competed across 20 sports in packed venues. The British media gave the event the coverage it deserved, and the achievements and stories of Paralympians were headline news – at both the front and back of all national newspapers. More broadcasters than ever before covered the London 2012 Paralympic Games. Television pictures were beamed to over 100 countries, reaching a cumulative audience of 3.8 billion people. By the time that Coldplay, Rihanna, and Jay-Z performed at the closing ceremony (see Figure 1.1),
### Table 1.1 History of the Paralympic Movement.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1922</td>
<td>Establishment of Comité International des Sports des Sourds/International Committee for Deaf Sports (CISS) [first international sports organization for people with disabilities]</td>
</tr>
<tr>
<td>1922</td>
<td>Establishment of the Disabled Drivers Motor Club (UK) [one of the earliest sports organization for people with physical disabilities (Brittain, 2010)]</td>
</tr>
<tr>
<td>1924</td>
<td>First International Games for the Deaf [first international sports event for people with disabilities]</td>
</tr>
<tr>
<td>1932</td>
<td>Establishment of British Society of One-Armed Golfers [one of the earliest organizations to emphasize sports of physical prowess for people with physical disabilities]</td>
</tr>
<tr>
<td>1939</td>
<td>Start of World War II [theaters of war led to a large increase in the number of fit, young soldiers and civilians sustaining permanent physical impairments, including spinal cord injury]</td>
</tr>
<tr>
<td>1944</td>
<td>Dr. Ludwig Guttmann begins tenure as inaugural Director of the National Spinal Injuries Unit in Stoke Mandeville, UK [Guttmann had free rein to develop and implement his quite radical approach to management of spinal cord injury (SCI). The inclusion of competitive sports activity was a key component of this approach that became increasingly important over the years]</td>
</tr>
<tr>
<td>1948</td>
<td>First Stoke Mandeville Games, an archery competition between patients from Stoke Mandeville and those at the Star and Garter Home in Richmond, Surrey, UK [occurred the same day as the opening ceremony of the London Olympic Games being held just 35 miles away, an important, though possibly coincidental, initial link with the Olympic movement (Brittain, 2010; Bailey, 2007)]</td>
</tr>
<tr>
<td>1949</td>
<td>Second Stoke Mandeville Games (known at the time as the “Grand Festival of Paraplegic Sport”; Brittain, 2010) [the Games became an established annual event and grew substantially, from 16 competitors and 2 hospitals, to 37 competitors from six hospitals (Brittain, 2010); Guttmann gives a speech in which he declares his hope that the Games would become international and achieve “world fame as the disabled men and women’s equivalent of the Olympic Games” (Goodman, 1986)]</td>
</tr>
<tr>
<td>1949</td>
<td>First Winter Games for the Deaf</td>
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<tr>
<td>1950</td>
<td>Ski School for amputees established in Salzburg, Austria [first winter sports organization for persons with a disability (Jahnke, 2006)]</td>
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<tr>
<td>1952</td>
<td>First International Stoke Mandeville Games (known at the time as the “First International Inter-Spinal Unit Sports Festival”; Bailey, 2007), with an official team from the Netherlands competing in a program of five sports [recognized as the first International Stoke Mandeville Games; first international games for athletes with a physical disability; second Stoke Mandeville Games to be held in the same year as the Olympic Games]</td>
</tr>
<tr>
<td>1953</td>
<td>First media record of the term “Paralympic,” in the Bucks Advertiser and Aylesbury News (Brittain, 2010)</td>
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<tr>
<td>1956</td>
<td>Fifth International Stoke Mandeville Games [the third Stoke Mandeville Games to be held in the same year as the Olympic Games]</td>
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<tr>
<td>1956</td>
<td>Guttmann awarded the Fearnley Cup by the IOC for “outstanding achievement in the service of Olympic ideals” [the first official engagement with the Olympic movement]</td>
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<tr>
<td>1957</td>
<td>The term “Paralympic” in common colloquial use to describe the Stoke Mandeville Games (Gold and Gold, 2007)</td>
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<tr>
<td>1959</td>
<td>Establishment of International Stoke Mandeville Games Committee, ISMGC (Bailey, 2007)</td>
</tr>
<tr>
<td>1960</td>
<td>1st Paralympic Games held in Rome (also officially known as the 9th International Stoke Mandeville Games); competitors were SCI athletes only [first International Stoke Mandeville Games held outside Stoke Mandeville; first time the Olympic Games and Stoke Mandeville Games were held in the same city, venue, and year, strengthening links between the movements; recognized by IPC as first Paralympic Games]</td>
</tr>
<tr>
<td>1960</td>
<td>Formal decision by International Stoke Mandeville Games Committee to align the International Stoke Mandeville Games with the Olympic cycle, so that in the year of an Olympic Games the Committee would endeavor to hold the annual Games in the same city (or country) as the Olympic Games</td>
</tr>
<tr>
<td>1964</td>
<td>2nd Paralympic Games held in Tokyo (also officially known as the 13th International Stoke Mandeville Games); competitors were SCI athletes only [ISMGC achieves goal of linking the Games with the Olympics, which it set in 1960; Paralympic athletes share accommodation and sporting facilities used by Olympic athletes]</td>
</tr>
<tr>
<td>1964</td>
<td>Establishment of International Sports Organisation for the Disabled (ISOD), a multi-disability sports organization that aimed to provide sports opportunities for people with disabilities other than SCI</td>
</tr>
<tr>
<td>Year</td>
<td>Event</td>
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</table>
| 1966 | • Ludwig Guttmann knighted for services to the disabled and becomes President of ISOD  
      • World Games for the Deaf replace International Games for the Deaf (established in 1924)  
      • First international sports competition for amputees, held at Stoke Mandeville and hosted by the British Limbless Ex-Serviceman’s Association (Brittain, 2010) |
| 1967 | • ISOD transfers headquarters to Stoke Mandeville  
      • ISOD begins development of rules of sports and classification for amputee athletes |
| 1968 | • 3rd Paralympic Games held in Tel Aviv, Israel (also officially known as 17th International Stoke Mandeville Games); competitors were SCI athletes only  
      [despite promising early negotiations with Instituto Mexicano de Rehabilitación, ISMGC fails for the first time to secure a host for the Games in Mexico, the 1968 Olympic City; credible alternative bids from Israel and USA indicate the growing international stature of the Games]  
      • Establishment of Sports and Leisure Group by International Cerebral Palsy Society |
| 1972 | • 4th Paralympic Games held in Heidelberg, Germany (also officially known as the 21st International Stoke Mandeville Games); competitors were SCI athletes only  
      • ISMGC changes name to International Stoke Mandeville Games Federation, ISMGF (Bailey, 2007) |
| 1975 | • United Nations (UN) General Assembly adopts “The Declaration on the Rights of Disabled Persons” (Resolution 3447, article 9), which states that “Disabled persons have the right to … participate in all social, creative or recreational activities” |
| 1976 | • 5th Paralympic Games held in Toronto, Canada (also officially known at the time as the Toronto Olympiad for the Physically Disabled, or Torontolympiad); competitors were SCI athletes and, for the first time, amputee and vision impaired (VI) athletes  
      [first Paralympic Games not recognized by the ISMGC alone, but in cooperation with ISOD; first games that included athletes other than those with SCI – viz. amputee and les autres (LA)]  
      • 1st Winter Paralympic Games held in Örnsköldsvik, Sweden (also officially known at the time as the “Winter Olympic Games for the Disabled”; Jahnke, 2006); competitors were amputee and VI athletes  
      • Establishment of Cerebral Palsy-International Sport and Recreation Association (CP-ISRA)  
      • UN adopted Resolution 31/123, declaring 1981 the International Year of Disabled Persons |
| 1977 | • ISOD creates Les Autres Classification system, a single classification system for athletes not eligible to compete in competitions for people with SCI, cerebral palsy, amputation, vision impairment, or hearing impairment (Bailey, 2007) |
| 1978 | • Establishment of Cerebral Palsy-International Sports and Recreation Association (CP-ISRA), replacing Sports and Leisure Group of the International Cerebral Palsy Society (established 1968) |
| 1980 | • 6th Paralympic Games in Arnhem, the Netherlands (also officially known at the time as Olympics for the Disabled); competitors were SCI, amputee, VI athletes, and, for the first time, athletes with cerebral palsy (CP)  
      • Establishment of International Blind Sports Association (IBSA)  
      [first international sports organization for people with vision impairment]  
      • 2nd Winter Paralympic Games held in Gelo, Norway (also officially known at the time as the 2nd Winter Olympic Games for the Disabled; Jahnke, 2006); competitors were amputee and VI athletes and, for the first time, athletes with SCI  
      • World Health Organization publishes International Classification of Impairment Disability and Handicap (ICIDH), which defines and uses a standardized language for describing the consequences of disease and injury; and provides a framework to code information relating to the consequences of disease and injury |
| 1982 | • Establishment of International Coordinating Committee of World Sports Organisations for the Disabled (ICC) comprised of representatives from CP-ISRA, IBSA, ISMGF, and ISOD (Bailey, 2007; Brittain, 2010)  
      • First Cerebral Palsy World Games, held in Denmark and hosted by CP-ISRA  
      • UN adopts Resolution 37/53, proclaiming 1983–92 the “United Nations Decade of Disabled Persons” |
| 1983 | United Nations declares Decade of Disabled Persons (GA resolution 37/52) |
| 1984 | • 7th Paralympic Games held in two locations:  
      ◦ New York, USA (also officially known at the time as the New York International Games for the Disabled); competitors were SCI, amputee, VI, CP, and, for the first time, LA athletes  
      ◦ Aylesbury, UK (also officially known at the time as International Stoke Mandeville Games); competitors were SCI athletes only  
      • 3rd Winter Paralympic Games, held in Innsbruck, Austria, also officially known at the time as the III World Winter Games for the Disabled (Jahnke, 2006); competitors were SCI, amputee, VI, CP, and, for the first time, LA athletes |
<table>
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<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1985</td>
<td>Establishment of International Association for Sport for Persons with Mental Handicap (INAS-FMH)</td>
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<tr>
<td>1986</td>
<td>CISS and INAS-FMH join ICC</td>
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<tr>
<td>1988</td>
<td>8th Paralympic Games held in Seoul, South Korea [first Games since 1964 held in the same city as the Olympic Games, sharing venues and facilities]; competitors were SCI, amputee, VI, CP, and LA athletes, and for the first time dwarves were included under the banner of LA</td>
</tr>
<tr>
<td>1989</td>
<td>Establishment of International Paralympic Committee (IPC)</td>
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<td>1990</td>
<td>ISMGF changes name to International Stoke Mandeville Wheelchair Sports Federation (ISMWSF)</td>
</tr>
<tr>
<td>1992</td>
<td>9th Paralympic Games, held in Barcelona, Spain; competitors were SCI, amputee, VI, CP, and LA</td>
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<tr>
<td>1995</td>
<td>CISS withdraws from Paralympic family, having joined in 1986</td>
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<tr>
<td>1996</td>
<td>10th Paralympic Games held in Atlanta, USA; competitors were SCI, amputee, VI, CP, LA, and, for the first time at the same venue, ID</td>
</tr>
<tr>
<td>1998</td>
<td>7th Winter Paralympic Games held in Nagano, Japan; competitors were SCI, amputee, VI, CP, LA, and, for the first time, ID</td>
</tr>
<tr>
<td>1999</td>
<td>INAS-FMH changes name to International Association for Sport for Persons with Intellectual Disability (INAS-FID)</td>
</tr>
<tr>
<td>2000</td>
<td>11th Paralympic Games held in Sydney, Australia; competitors were SCI, amputee, VI, CP, LA, and ID</td>
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<tr>
<td>2001</td>
<td>INAS-FID suspended from the Paralympic Movement by the IPC at the 2001 General Assembly following revelations that 69% of athletes who had won medals in the intellectually disabled events at the Sydney Paralympic Games did not have a necessary verification of an intellectual disability</td>
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<tr>
<td>2002</td>
<td>Deaflympics replace World Games for the Deaf (established in 1966)</td>
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<tr>
<td>2003</td>
<td>8th Winter Paralympic Games held in Salt Lake, USA; competitors were SCI, amputee, VI, CP, and LA</td>
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<tr>
<td>2004</td>
<td>A cumulated global television audience of 1.8 billion watch the Athens 2004 Paralympic Games in which judo and women's sitting volleyball make their Games debut and at the closing ceremony the Agitos, the new symbol of the Paralympic Movement, is launched</td>
</tr>
<tr>
<td>2006</td>
<td>Cairo, Egypt, stages an IPC Extraordinary General Assembly adopting a new IPC Constitution and new nomination and election procedures for the Governing Board, which will replace the Executive Committee</td>
</tr>
<tr>
<td>2007</td>
<td>IPC Table Tennis transfers governance to the International Table Tennis Federation (ITTF) and IPC Cycling becomes part of the Union Cycliste Internationale (UCI)</td>
</tr>
<tr>
<td>2008</td>
<td>Seoul, South Korea stages the 13th IPC General Assembly; new members include Liberia, Panama, the Netherlands (transfer), Asian Paralympic Committee, FEI, FISA, ITTF, and UCI (there are now 178 members)</td>
</tr>
<tr>
<td>2009</td>
<td>The IPC Classification Code is approved by the General Assembly and published; it helps support and coordinate the development and implementation of accurate, reliable, and consistent sport-focused classification systems, and to detail policies and procedures common to classification in all sport</td>
</tr>
<tr>
<td>2010</td>
<td>For the first time, the Parapan American Games are held in the same city and at the same venues as the Pan American Games; Rio de Janeiro, Brazil welcomes 1,132 athletes from 25 countries</td>
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<td>2011</td>
<td>Bonn stages the first Women in Paralympic Sport Leadership Summit</td>
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### Table 1.1 (Continued)

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<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>2008</td>
<td>• 13th Paralympic Games held in Beijing, China; high jumper Hou Bin climbs a rope using just his arms in the Bird’s Nest Stadium to light the Paralympic Cauldron during the opening ceremony; rowing makes its Paralympic Games debut</td>
</tr>
</tbody>
</table>
| 2009 | • INAS-FID reinstated to the Paralympic movement at the IPC General Assembly  
• Sir Philip Craven re-elected President, Australian Greg Hartung becomes Vice President, and the membership votes in a new Governing Board  
• The process of complying with the IPC Classification Code is initiated through a self-audit process; a total of 157 NPCs, 4 regions, 3 IOSDs, and 10 IFs sign the Code for acceptance |
| 2010 | • Vancouver, Canada stages the 10th Paralympic Winter Games attracting 502 athletes from 44 countries; the cumulated global television audience hits 1.6 billion people |
| 2011 | • Fifth VISTA Conference held in Bonn, Germany |
| 2012 | • 13th Paralympic Games held in London, UK; competitors were SCI, amputee, VI, CP, LA, and ID  
• The IPC and IOC sign a new cooperation agreement that increases the amount of financial support to the IPC and guarantees that the Paralympics will be staged in the same city and venues as the Olympics through until Tokyo 2020  
• The Agitos Foundation is launched aiming to be the leading global organization developing sport activities for people with an impairment, as a tool for changing lives and contributing to an inclusive society for all |
| 2013 | • Sixth VISTA Conference held in Bonn, Germany  
• In Athens, Greece, Sir Philip Craven is elected IPC President for a fourth and final term at the 16th IPC General Assembly, and Brazilian Andrew Parsons wins the race to become Vice President |
| 2014 | • 11th Winter Paralympic Games held in Sochi, Russia; competitors were SCI, amputee, VI, CP, and LA, and exceed all expectations, obliterating all ticket and television audience records for a Winter Games  
• IPC celebrates its 25th anniversary |
| 2015 | • Seventh VISTA held in Girona, Spain |
| 2016 | • 14th Paralympic Games held in Rio de Janeiro, Brazil |
| 2018 | • 12th Winter Paralympic Games held in PyeongChang, South Korea |
| 2020 | • 15th Paralympic Games held in Tokyo, Japan |


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**Figure 1.1** London 2012 Paralympic Games. *Source:* Getty Images. Reproduced with permission of Getty Images.
few observers could believe what had taken place in the previous 12 days. London 2012 chairman Lord Sebastian Coe, speaking on the first anniversary of the Games, said: “What struck me most was that people were not seeing the disabilities: they were seeing the abilities. These were athletes performing feats that so-called ‘able-bodied’ people would not have got within a country mile of.” Post-Games research found that fantastic athletic performances, combined with capacity crowds and unprecedented media coverage, led to a huge shift in British society. One in three UK adults changed their attitude toward people with an impairment, while two in three said that the Paralympic Games changed the way people with an impairment are viewed in Great Britain. Very many aspects of London 2012 have set the benchmark for how future Paralympic Games should be organized.

**Historic “One Bid, One City” agreement**

Since their inception in 1960, the Paralympic Games have always been held in the same year as the Olympic Games. In Rome 1960 and Tokyo 1964, the Games took place in the same city as the Olympics, but that practice was not repeated until Seoul 1988 for the Summer Games, and Albertville 1992 for their winter equivalent. Since then, the Paralympics have been staged in the same city as the Olympics, with just a few weeks separating the two major sport events. However, it was not until 2001 that a formal agreement was put in place between the International Olympic Committee (IOC) and the IPC, ensuring that Olympic host cities would also stage the Paralympics.

On June 19, 2001, Dr. Bob Steadward, the IPC’s Founding President, and IOC President Juan Antonio Samaranch signed the historic agreement that still benefits the Paralympic Movement to this day. The “One Bid, One City” agreement protected the organization of the Paralympic Games, meaning that the staging of the Paralympics is automatically included in the bid for the Olympic Games. It formally recognized that, after 2008, the Olympic host city had an obligation also to stage the Paralympic Games, using the same venues, facilities, and infrastructure (see Figure 1.2). The agreement also addressed the general scope and organization of the Paralympic Games, with the aim of creating similar principles for the organization of the Olympic and Paralympic Games. Although this had been the informal practice since 1988, cementing this bond in the eyes of organizing committees and the public was an important step. The agreement also meant that, from the 2012 bid process, cities were fully aware that they were bidding for both Games, not just the Olympics. Speaking after signing the agreement, President Samaranch said: “Today is an important day for the Olympic Movement. This agreement is the result of many years of close relationships between the IOC and the IPC. Its aim is to secure the organization of the Paralympic Games, with full integration of both organizing committees and financial guarantees.”

Since the Salt Lake City 2002 Games, one organizing committee has been responsible for hosting both the Olympic and the Paralympic Games. Athletes from both Games live in the same village and enjoy the same catering services, medical care, and facilities. Ticketing, technology, and transport systems for the Olympic Games are seamlessly extended to the Paralympics. Over the years, the agreement has been extended on a number of occasions. The most recent extension was signed in June 2012, going through to Tokyo 2020.

**Barcelona 1992: The benchmark for the future**

Barcelona 1992 acted as a turning point for the entire Paralympic Movement, and is still referred to today as the best Games ever by many who witnessed what took place in the Catalan capital (see Figure 1.3). For the first time ever the Games benefited from daily live domestic television coverage. They were played out in front of packed venues and, in some areas, received comparable levels of organization and service to the Olympics. The performances of both Olympians and Paralympians were greeted with the same level of enthusiasm and support. Moreover, a Paralympian took center stage before the event started, with Para-archer Antonio Rebello responsible for lighting the cauldron during the Olympic opening ceremony. His extraordinary aim saw him shoot his arrow high above the
Olympic stadium. Four weeks later Rebello stood in the same position, only this time to light the Paralympic flame in front of a 65,000-capacity crowd during a spectacular Paralympic opening ceremony. Among those watching were IOC President Juan Antonio Samaranch, King Juan Carlos, and Queen Sofia of Spain.

Coach’s Corner

“The Paralympic Games in Barcelona were the first of their kind, crowned with success which highlighted to the world the human quest for great sporting achievements.”

Juan Antonio Samaranch, IOC President

Barcelona Mayor Pasqual Maragall, who was highly supportive of the Games, noted that “the city took a whole-hearted interest in the competition.” Although tickets for both the sold-out opening and closing ceremonies came at a price, tickets for all 16 sports were made available free of charge. The Spanish public responded, and a record 1.5 million people attended the Games. Many venues were regularly filled with hugely passionate crowds. Long queues developed for any sport involving Spanish teams or athletes, and it was not uncommon for people to be turned away, such was the demand for a seat. The USA beat 82 other countries to top the medal standings, helped in part by visually impaired swimmer Trischa Zorn, who won ten gold and two silver medals. Other highlights included the thrilling finale to the men’s wheelchair marathon, which took place in front of 65,000 spectators in the Olympic Stadium, and the men’s wheelchair basketball final, which took place in front of a 15,000-capacity crowd ahead of the closing ceremony. Barcelona 1992 were the last Games to be organized by the International Coordinating Committee (ICC), following the formation of the IPC in 1989, and benefited hugely from the financial support of the ONCE Foundation.
Jonnie Peacock silences 80,000 people

It is amazing how less than 11 seconds can change everything. At London 2012, British sprinter Jonnie Peacock delivered a performance that not only changed his own life for ever, but was arguably the greatest single moment in Paralympic sporting history. At the start of 2012, the T44 sprinter was a relative unknown. His only major international result was a sixth-place finish at the 2011 World Championships. In June 2012, however, things started to change. Peacock, then aged 19, ran the 100 meters in 10.85 seconds to become the world’s fastest leg amputee. With a world record under his belt, he started a gradual rise to fame in the lead-up to London 2012, starring in a Channel 4 television commercial promoting the Games and being talked about as a gold medal prospect. Yet few could have predicted what happened next. When eight athletes lined up for the men’s 100 meters T44 final – the most anticipated race of London 2012 – the crowd was already excited after watching David Weir win his third gold of the Games with a virtuoso performance. The competition was fierce. Nobody could predict the podium positions, and defending champion Oscar Pistorius and world champion Jerome Singleton were considered to have an outside chance. Unbelievable tension settled on the stadium as the athletes took to the starting blocks, but it was broken by 80,000 people chanting “Peacock, Peacock, Peacock.”

The emotion was raw, and every spectator felt part of the race. London 2012 chief Lord Sebastian Coe said: “Even the great Usain Bolt doesn’t get his name chanted in the way Jonnie Peacock did. It was spine-tingling stuff.” Peacock calmed the crowd, somehow coping with the immense pressure with ease. A stumble by Alan Fonteles Oliveira on the start line only added to the tension. Then, as the starting gun sounded, the athletes exploded into a 1.6 meters/second headwind. Peacock, however, had a tailwind of 80,000 screaming fans urging him
to the finish line. As the line approached he took a sneaky look to his left: there was nobody ahead of him. A glowing smile replaced the tension on his face. He knew that he was going to be Paralympic champion (see Figure 1.4). Peacock crossed the line in 10.90 seconds, a Paralympic record, and the stadium went ballistic. The USA’s Richard Browne took silver, marking the start of his huge rivalry with Peacock, while South Africa’s Arnu Fourie claimed the bronze. All eight finishers came in under 12 seconds. Peacock said: “To hear the crowd chant my name was amazing, and that’s going to live with me forever. I couldn’t have wished for better.”

**Sydney 2000**

After the tremendous success of Barcelona 1992, and the interesting experience of Atlanta 1996, the Sydney 2000 Paralympic Games got the Paralympic Movement back on track with a sensational showcase of sport (see Figure 1.5). The momentum of a highly successful Olympics transferred to the Paralympics, and astounding levels of competition, administration, and public awareness raised the profile of the Paralympic Games to a new high.

From an organizational point of view, the Games were outstanding. The local organizing committee benefited from a number of shared resources with the Olympics. A record 1.2 million tickets were sold, and many spectators received excellent explanatory guides to athlete classification. The spectacular opening ceremony was a three-hour affair. One of Australia’s most decorated Paralympians, Louise Sauvage, lit the Paralympic cauldron, and pop princess Kylie Minogue entertained the fans with a virtuoso performance. The Games attracted 3,881 athletes from 122 countries, greater than the number of athletes and countries that took part in the Munich 1972 Olympic Games. Athletes
competed in 18 sports and, in terms of sporting performance, Canadian para-swimmer Jessica Sloan won the most individual titles, topping the podium six times. Great Britain’s wheelchair racer Tanni Grey-Thompson also enjoyed notable success, winning four gold medals. After being a demonstration sport in Atlanta, wheelchair rugby made its full Games debut and won huge praise for its fast and physical style. The USA edged out Australia 32–31 in a thrilling gold medal match. Despite the loss, Australia, aided by tremendous home support, still topped the medals table, winning 149 medals, including 63 golds. The Games were not without controversy, however. It was discovered that members of the gold medal–winning Spanish basketball team for athletes with an intellectual impairment did not meet the eligibility criteria.

The Games received unprecedented global exposure. More than 2,300 media representatives attended and, for the first time ever, 100 hours of Paralympic sport were webcast to more than 103 countries, ensuring that those in territories where the Games were not shown on television could still follow the action. The official Games website attracted an estimated 300 million visits during competition time. At the closing ceremony on October 29, which featured live music and a showcase of the athletes’ achievements, IPC President Dr. Bob Steadward said: “It came as a sheer delight, but no surprise, that you excelled yourselves in hosting our Paralympic athletes to an absolutely outstanding event. Thank you Australia, for enhancing the profile of our athletes more than at any time in our history.”

**Great Wall of China and Forbidden City made accessible**

A sporting event’s success is usually judged by similar metrics: the performances of athletes, number of television hours broadcast, media coverage achieved, spectator attendance, and commercial
income generated. What makes the Paralympic Games unique is the legacy that they can leave away from sport, and their ability to act as a catalyst for enormous societal change. Prior to the Beijing 2008 Paralympic Games, China’s 83 million people with an impairment were excluded from society. The country was inaccessible, inhospitable, and in many ways inhumane for anyone with an impairment. Winning the right to host the 2008 Paralympics Games, however, acted as a trigger for the Chinese government to improve the lives of people with an impairment and protect their rights as equal members of society.

To meet the requirements of the Games, new legislation on the building of accessible facilities was passed. A 5,000-strong team was recruited to oversee the construction and renovation of accessible facilities. In the seven years leading up to the Games, RMB 1 billion – equivalent to EUR 124 million (USD $136 million) and the sum of the last 20 years’ investment – was spent on making 14,000 facilities, including roads, transport hubs, and public buildings, accessible throughout China. More than RMB 67 million (USD $11 million) was spent on making 60 of the country’s most popular tourist destinations accessible. Elevators and wheelchair ramps were installed at the most popular part of the Great Wall of China, and accessibility was also improved in the 600-year-old Forbidden City and Imperial Palace (see Figure 1.6). On July 1, 2008, the revised Law of the People’s Republic of China on the Protection of People with a Disability came into force, having been adopted by the National People’s Congress Standing Committee some months earlier. The law provided that state and society should take measures to improve accessible facilities and promote accessible information, in order to enable equal participation in social life for people with an impairment. One small example was allowing guide dogs and their owners into public places. This is

Figure 1.6  Great Wall of China and Forbidden City become accessible during the Games. © International Paralympic Committee.
taken for granted in many countries, but was completely new for China.

Coach's Corner

On July 1, 2008, the revised Law of the People’s Republic of China on the Protection of People with a Disability began to be enforced. China was also among the first signatories of the United Nations Convention on the Rights of Persons with Disabilities, the first international human rights treaty, which came into effect on May 3, 2008. Thanks to the Paralympic Games, people in China now have a greater knowledge and understanding of disability. Those with a disability now enjoy a better social status, more public attention, greater respect, improvement of social security, easier access to employment, better educational opportunities, and much more. Had Beijing not staged the 2008 Paralympic Games, such monumental change would not have taken place.

First IPC–IOC agreement

After years of working together informally, the IPC and IOC signed a historic Memorandum of Understanding (MOU) in 2000 covering the basic principles and relationships between the two bodies. Signed by founding IPC President Dr. Bob Steadward and IOC President Juan Antonio Samaranch (see Figure 1.7), the agreement arose from the IOC 2000 Commission, of which Dr. Steadward was a member. The Commission recommended that the Paralympics must be organized in the same city as the Olympic Games, and that the obligation for the host city to organize the Paralympic Games must be included in the host city contract; the Paralympic Games will always follow the Olympic Games; the IPC will have a representative on both the IOC Evaluation Commission and the Coordination Commission; and the Paralympic Movement, through a member of the IPC and Paralympic athletes, could be represented on the IOC. Similarly, the Olympic Movement could be represented on the IPC.

The MOU was in two parts, the first of which was signed during the Sydney 2000 Paralympics. It included statements of shared philosophy, which made clear that both organizations support “the right of all human beings to pursue their physical and intellectual development.” It also incorporated matters of protocol, accreditation, funding, administrative relationships with staff, and information technology. In October 2000 Dr. Steadward was elected an IOC member, a role to which Sir Philip Craven was also elected when he took over as IPC President in 2001. The second part of the Agreement was signed in June 2001, and protected the future of the Paralympic Games. It formalized the practice of “One Bid, One City” and meant that any city hosting, or bidding for, the Olympic Games automatically had to include the Paralympics too.

Since the historic first agreement in 2000, the IPC’s relationship with the IOC has grown stronger each year. The “One Bid, One City” concept has been extended on a number of occasions, most recently in June 2012 to cover the 2018 and 2020 Games. The latest agreement, signed prior to the London 2012 Olympics, also provides the IPC with greater financial support and brand protection for the Paralympic Movement, and includes further cooperation on a range of other areas.

Sochi 2014 breaks down barriers

The Sochi 2014 Paralympic Winter Games (see Figure 1.8) were a stunning success, exceeding all expectations. The athletes arrived at the Games as the best prepared ever, and they did not disappoint. Few observers will forget the stand-out performances of Russia’s Roman Petushkov winning a record six Nordic skiing golds, or Anna Schaffelhuber, the German sit skier, winning five gold medals from five events. In a Games of many highlights, one of the best was the vocal crowds and packed venues that became a trademark of Sochi 2014. A record 316,200 tickets were sold, a figure that was almost 40% higher than had been achieved at Vancouver 2010.

Traditionally, Russian spectators only cheer their own athletes. Nevertheless, they were quickly infected by the Paralympic spirit, supporting and celebrating the performances of every single athlete. This unified support climaxed on the final night of competition, when Russia met the USA in the ice sledge hockey gold medal match. The crowd
Figure 1.7  First IPC-IOC Agreement signed by IPC President Dr. Bob Steadward and IOC President Juan Antonio Samaranch. © International Olympic Committee.

Figure 1.8  Sochi 2014 breaks down barriers. © Sochi 2014.
were delirious in their support of the Russian team. What was most impressive, however, was their reaction at the end of the game, when they stayed to cheer all three medal-winning teams. The support was for the sport and the athletes. It did not matter which country they represented: everyone was a hero. The Russia–USA match also marked one of the most historic moments in Paralympic broadcasting history: it was the first time that any US gold medal success had been shown live on the US television channel NBC. The Games also received more coverage than ever before, with television pictures shown on 125 channels in 55 countries. Consequently, the Sochi 2014 Paralympic Winter Games were the most watched in history, attracting a global cumulative audience of 2.1 billion people.

However, the biggest impact of Sochi 2014 was on the Russian government and Russian society. In 1980 the old USSR had declined the opportunity to stage the Paralympics because the government said that the country had nobody with an impairment. Thirty years later, the attitude could not have been more different. The driver behind this change was the Games. Sochi’s election as host city in 2007 led for the first time to Russian authorities and society paying attention to the issue of inclusion, and creating accessible environments for all. New legislation was passed at the highest levels of government, and the Sochi 2014 organizing committee created a barrier-free infrastructure, ensuring that everything built for the Games was completely accessible. Sochi is now a blueprint for the rest of Russia, with 200 cities already using what was created for the Games as a guide for furthering their own accessibility. The lives of millions of Russians will be permanently improved and enriched.

**The IPC is created in Düsseldorf**

The German city of Düsseldorf hosted the historic meeting in 1989 that saw the formation of the International Paralympic Committee. The aim of the meeting, which was attended by 203 participants from 42 countries, including West German Chancellor Helmut Kohl, was to form a new world organization for sports for athletes with a disability. It was a tense and fraught meeting, with existing organizations airing their fears of losing prominence within any new body. Nevertheless, a vote was taken, and the official founding of the International Confederation of Sports Organizations for the Disabled (ICSOD) was confirmed (see Figure 1.9). A new organization had been created. It was soon agreed to change the name to the International Paralympic Committee, which would be “the only World Multi-Disability Organization with the right to organize the Paralympic and Multi-Disability World Games, as well as World Championships.”

The next steps were to elect an Executive Committee and agree on the constitution. The Executive Committee, made up of a President, two Vice Presidents, a Treasurer, a Secretary General, three Members at Large, and a Technical Officer, would be elected by the General Assembly. There were also to be six representatives of the regions elected by the regions, one athlete representative voted for by athletes, and six representatives appointed by the six international organizations of sports for athletes with a disability. The role of the Executive Committee, led by founding President Dr. Bob Steadward, was to “initiate studies and make decisions on the policy as dictated by the General Assembly, respond to the needs of the members, set out rules for sanctioning international events, and ensure all complied with rules laid out by the IPC.”

The International Committee for Deaf Sports, Cerebral Palsy International Sports and Recreation Association, International Blind Sports Association, International Association for Sport for Persons with Mental Handicap, International Stoke Mandeville Games Federation, and International Sports Organization for the Disabled would be celebrated as Founding Members of the IPC, and the voting rights and representation of all members were determined. Full national members of the IPC could participate in all international competitions in all sports, and the separate international federations retained the right to organize their own events that were separate from the Paralympic Games. The IPC was initially registered and housed in Brugge, Belgium as an international nonprofit organization, and shared office space there with the Flemish League for Sports for People with a Disability. The IPC was always an athlete-centered organization, and in 1990 the first Athletes
Committee was elected, with Martin Mansell as Chairperson.

**Hou Bin becomes a global sensation**

After three years of planning and a full year of rehearsals, the opening ceremony of the Beijing 2008 Paralympic Games took place on September 6 in the immense Bird's Nest stadium. A crowd of 90,000 spectators witnessed a sensational ceremony that drew on the themes of sky, earth, and humans, and aimed to showcase to the world the Paralympic spirit and Chinese culture. The colorful and memorable production involved over 4,800 performers, 850 of which had an impairment, and featured the most spectacular lighting of a Paralympic cauldron in the history of the Games.

Hou Bin, a Chinese high jumper who had won Paralympic titles at three consecutive Paralympic Games from Atlanta 1996 through to Athens 2004, was chosen as the person to light the cauldron. What he did in doing so left the whole world in awe, and showcased to the world the ability of Paralympic athletes to push their bodies to the absolute limit. With the Paralympic torch fixed to his wheelchair, Bin used his bare hands and every ounce of energy in his body to haul himself and his wheelchair 39 meters into the air and light the cauldron on the stadium roof (see Figure 1.10). It was an unbelievable moment, and one that epitomized all four of the Paralympic values of courage, determination, equality, and inspiration. The awe-inspiring sight was one that the Paralympic Movement, and the global audience watching on television, would never forget. Cheered on by a crowd who could not believe what they were seeing, Bin took over three-and-a-half minutes to climb the rope to the roof. By the time he reached the summit, he was exhausted. He took a deep breath, composed himself, and then lit the cauldron, to a thunderous roar from the enormous crowd. It was a symbolic moment, and one that marked the start of the Games that would change Chinese society for ever.
Yet Bin’s achievement was even more remarkable than it first appeared: he completed the climb with a broken finger, suffered days earlier during a rehearsal. IPC President Sir Philip Craven said: “To watch him climb a rope from the stadium floor to the roof, with a broken finger rubbing on the rope, and with a flame on his chair, was one of the most amazing things I’ve ever seen. That was the Paralympic spirit in action.”

The unique challenges of classification

During the early years of the Paralympic Movement, it became clear that athletes had to be put into classes (see Chapter 7), not unlike scientific taxonomic classifications that group things according to their similarities and not their differences. There are many examples in botany, zoology, and even pathology. However, the classification of athletes proved to be more challenging. Each evolution of Paralympic classification was to “promote fair and equitable competition,” but as the movement matured it became clear that certain models of the time were not creating fair and equitable competition and had to be continuously evaluated and modified.

In the 1970s and into the 1980s, a medical model was established for athlete classification. Adopting a replication used in rehabilitation hospitals of the time, units for spinal cord injury, amputation, brain injury, other neurological, and orthopedic conditions created a class based on the medical diagnosis, with a single class used for all sports. In the 1980s there was a transition from medical to “sport-specific functional systems,” which resulted in fewer classes than the medical systems and
created in the 1988 Seoul Paralympic Games a shift from sport as rehabilitation and recreation to elite sport. By the 1992 Barcelona Paralympic Games, all sports were using sport-specific functional classification systems. Some challenges began to occur when it was recognized that the classification of athletes was based on the experience and judgment of classifiers who may not always have used objective criteria.

In 2003, the IPC developed a strategy to create a system that was “accurate, reliable, consistent and credible,” and this led to the publication of the 2007 IPC Classification Code. The Classification Code set out to standardize jurisdiction, terminology, eligibility (minimum eligibility), operational procedures (such as athlete assessment, protests, and appeals), misrepresentation of ability, and classifier certification across all sports (for more extensive information, go to http://www.paralympic.org/Classification/Code). While there are many important points to be made regarding the Classification Code, Table 1.2 indicates the key standards that make this an important document.

In 2011, Tweedy and Vanlandewijck published a paper titled “International Paralympic Committee Position Stand – background and scientific rationale for classification in Paralympic sport,” which has become the standard reference for evidence-based classification. Each sport’s classification system must now match the standards identified in the Position Stand. Tweedy and Vanlandewijck (2011) explain that the purpose of evidence-based classification in Paralympic sport is to “promote participation in sport by people with disabilities by minimizing the impact of eligible impairment types on the outcome of competition,” which ensures that the success of an athlete is determined by skill, fitness, power, endurance, tactical ability, and mental focus.

The ten eligible impairments for inclusion in the Paralympic Games are identified in Table 1.3. While these have been identified, not every Paralympic sport is obligated to include every impairment type. The IPC Classification Code does require, however, that the type of impairment be permanent. Each International Sports Federation determines which impairment type to include and the minimum impairment criteria (how severe an impairment has to be for an athlete to compete).

### Are cyborg athletes in our future?

While issues regarding technology are covered in Chapter 8, the idea of a cyborg athlete in the future has engaged the Paralympic Movement in discussion of both classification and ethics. As far back as 1948 at those first archery competitions between patients from Stoke Mandeville and the Star and Garter Home, no one, including Dr. Ludwig Guttmann, would have dreamed of the technological advances that would be made in just a few short decades. During this time, many people believed that the introduction of advanced technologies (e.g., running blades) was just an evolution of sport, while others held that rules should be put in place where a prosthetic would not predict the outcome of a race or contest. The world outside of sport for athletes with an impairment did not enter the conversation until the 2008 Beijing Olympic Games, when South African sprinter Oscar Pistorius competed in the Olympic sprint relays. Never before had an athlete competed with a prosthetic limb, so a great debate ensued as to his eligibility to compete in the Olympic Games. There was little conversation, however, about him and his running

### Table 1.2 Key Classification Code standards.

| 2.1.1 – Classification is undertaken to ensure that an Athlete’s impairment is relevant to sport performance |  |
| 2.1.2 – Classification has two important roles: |  |
| ● To determine eligibility to compete |  |
| ● To group athletes for competition |  |
| 15.2.2 – International Federations should develop evidence-based classification systems through research |  |


### Table 1.3 Eligible impairments

<table>
<thead>
<tr>
<th>Impaired strength</th>
<th>Hypertonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impaired range of movement</td>
<td>Ataxia</td>
</tr>
<tr>
<td>Limb deficiency</td>
<td>Athetosis</td>
</tr>
<tr>
<td>Leg length difference</td>
<td>Vision impairment</td>
</tr>
<tr>
<td>Short stature</td>
<td>Intellectual impairment</td>
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</table>

Are cyborg athletes in our future?

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blades competing in the Paralympic Games. Perhaps there should be more discussion, since because of the IPC’s desire to “ensure competition is fair and equal, all Paralympic sports have a system in place which ensures that winning is determined by skill, fitness, power, endurance, tactical ability and mental focus, the same factors that account for success in sport for able bodied athletes” (Tweedy and Vanlandewijck, 2011).

Soon the cyborg athlete will need to be studied. Technological advances coupled with the high stakes of Paralympic sport (including financial rewards) will mean that scientists and athletes will come together to try to find the winning edge. New terminology has been developed, including the cyborgization of sport and posthumanization. Ethical considerations will need to be determined, which may include stump length for amputee athletes when undergoing surgery. We do not know what the future holds; perhaps the cyborg athlete will be in our future. But, unlike the introduction of running blades, the Paralympic Movement needs to be ready for it. Either way, the Paralympic Movement has been jettisoned into the international spotlight courtesy of great athletic performances and the growing interest of news media around the world. Finding the winning (scientific) edge will be on every athlete’s mind, and the Paralympic Movement must be ready.

Conclusion

This introductory chapter has provided a brief history of a movement that has a relatively short history and has highlighted two important strategies for future success. Classification and technology are discussed every day as athletes continue to improve and, it seems, to shatter world records at every national and international competition. Athletes are training harder and are more dedicated to their sport than ever before. The International Paralympic Committee has a dedicated team of full-time professional staff and volunteers who work tirelessly to bring to the world the very best competitions. This book will help to guide the coach and the athlete to be the very best they can be within the rules of competition. It is also designed to stimulate conversation among the scientific community to engage even more research scientists to study these remarkable athletes. The world’s spectators are involved, as evidenced by sold-out crowds not only at Paralympic Games but at regional events as well. Television rights have already been established well past the next quadrennial. If you are a coach, an elite athlete, or someone who wants to begin an athletic career, this book is for you.

References


Recommended reading


Chapter 2
Biomechanics and ergonomics

Helco van Keeken, Sonja de Groot, Riemer Vegter, and Lucas van der Woude
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Introduction

Paralympic sports constitute human movement activities at the highest critical level of individual movement actions, exercise, and behavior. Athletes are dealing with abilities such as power production, pacing, skill, and precision, as well as game strategy. The complexity of talent and individual characteristics besides environmental conditions will define performance. Performing elite Paralympic sports activities, like running with a prosthetic limb or wheelchair track racing, requires an array of specific abilities. Talented athletes can only acquire these extraordinary abilities during extensive physical and mental practice using optimal – that is, individually fine-tuned – assistive technology. During such exercises and practice sessions, systematic monitoring of relevant performance measures will help to facilitate effective training and eventually can help to win the race or contest.

Sports performance, and how to improve it, can be studied from different disciplinary perspectives such as sociology, psychology, philosophy, biomedicine, (exercise) physiology, biomechanics, ergonomics, or combinations of these. Understanding sports performance as a Paralympic sports scientist, coach, or athlete through observation within each of these disciplines will help to refine individual or team sports performance.

Studies from biomechanics and ergonomics are critical for the study of power production, speed, timing, technique, coordination, precision, and strategy during sports events or training. A better understanding of these measures and their underlying mechanisms will help to improve performance when it matters, will contribute to the athlete’s health, and is expected to help prevent injury. The conceptual model in Figure 2.1 highlights the complex interplay of different physiological and biomechanical factors that ultimately influence the ergonomics of wheelchair sports in the context of safety, health, and comfort, as well as efficiency and sports performance.

How a selection of these factors can have an impact on sports performance and injury prevention in amputee running and wheeled sports will be explained in further detail in this chapter. Other chapters explain the interactions between training, psychological preparation, medical interventions, classification, and many other topics influencing the training and coaching of Paralympic athletes.

Biomechanics

Many of the factors that determine Paralympic performance during a race or in a game can
be explained from a biomechanics perspective. Insights into the biomechanics of Paralympic athletic performance and the involved assistive technology or equipment help with the development of an appropriate training and game plan. Biomechanics, the theory of mechanical laws applied to the biological system, can be divided into different subdisciplines. This chapter primarily provides an overview of the role of the two classic biomechanical subdisciplines, kinematics and kinetics. Practical implications for Paralympic sports performance and health preservation are also provided. The biomechanics of amputee running and wheeled sports are presented sequentially, with a predominant starting role for time and speed and other kinematic characteristics of amputee running, while energy preservation and power output are taken as key points in wheeled sports performance.

**Coach's Corner**

Game performance and training can be improved based on biomechanical insights. A basic understanding of the effect of the underlying forces causing movement helps during the development of an appropriate training plan.

**Ergonomics**

Related to biomechanics, but enveloping a much broader range of scientific disciplines, ergonomics strives for optimization of human functioning with or without assistive technology, and aims to improve individual performance, health, safety, and well-being in any daily life task and environment. Optimization of functioning – through fine-tuning of the athlete, the assistive or sports
Biomechanics and ergonomics technology (e.g., prosthetic device or sports wheelchair), and the interface between human and technology (e.g., prosthetic socket foot, ankle or knee joint; wheelchair seat/backrest or handrim configuration) and/or environment – is key to sports ergonomics, which clearly also builds on our biomechanical understanding of Paralympic sport.

Coach's Corner

Fine-tuning of assistive technology toward the Paralympic athlete's needs is essential for optimal individual functioning. A properly aligned prosthetic device or wheelchair increases user efficiency and enhances athletic performance.

This ergonomic approach brings into play the need for increased awareness of overuse problems (e.g., musculoskeletal issues in the sound or amputated leg as well as socket-related impact or friction injury) in amputee running as well as in wheelchair racing (e.g., shoulder- or wrist-related problems, musculoskeletal problems, back injuries, as well as push-impact-related injury to the hands). These self-evident examples become more complex in outcome when the mechanical interplay of foot or knee-joint design and its fine-tuning are considered, or when the wheelchair design and interfacing characteristics in an individual racer are involved.

Biomechanics in Paralympic sports

Insights into the biomechanics of Paralympic performance help in the development of appropriate training, in the fine-tuning of assistive technology, and in winning the match, race, or team sport. In athletics track events, a win is clearly defined as the shortest time to cover a preset distance while starting from a static position. Therefore the position of an athlete, its first derivative – velocity (change of position over time) – and its second derivative – acceleration (change of velocity over time) – are often the first biomechanical aspects of interest to the coach and athlete. For instance, when competing on a running track or court, the athlete wants to be at a certain place in less time than his or her opponents. That means that when the same distance is covered, the average velocity must be higher. Furthermore, acceleration (i.e., the rate at which the velocity of an athlete changes over time) is very important in sports. For example in (wheelchair) ball sports, when the athlete is able to accelerate faster than the opponent and maintain that velocity, he or she will lose the defender quickly and a fast break and scoring opportunity might be possible.

Coach's Corner

Today's advanced technology helps coaches and athletes to apply simple biomechanical principles and theory to improve individual sport performance. The motions observed by coaches can be objectified, analyzed, and used for performance evaluation.

Kinematics and kinetics of running

Kinematics is the mechanical discipline that describes the motion of points, bodies (objects), and systems of bodies (groups of objects) without consideration to the causes of motion. Kinematics is universal and can be used to evaluate, for example, running and sprinting with a prosthetic limb (or a wheelchair for that matter), which are noticeably different compared to gait, not only in able-bodied athletes, but also in athletes with a lower-limb amputation. By registering the position of the athlete over time, the velocity and the accompanying accelerations can be studied. The time it takes to run a certain distance can be easily assessed using a stopwatch or timing gates. However, if a coach wants to measure velocity changes or accelerations, other sensors with a higher resolution or video have to be used.

Nowadays a variety of sensor systems is available that can help determine changes in velocity. Smartphones or tablets can be used in combination with commercially available “apps.” Using video options in a smartphone or tablet also allows two-dimensional (2D) tracking of kinematics, which means an action in a planar framework. Beyond
that, more professional kinematic data can be obtained using high-speed video or different optoelectronic camera systems. Using Global Positioning Systems (GPS) in the smartphone allows more global analysis of position and speed, where local positioning systems can be used during a practice session of track athletes or in game actions or events in a court or a confined space. With the data coming from these devices and kinematic equations, many aspects of an athlete’s performance can be evaluated. The data provide information about how an athlete builds up a race from start to finish, when and where the athlete accelerates and decelerates, what the current velocity is during the race, how a bend or curve influences the velocity, and what the influence is of the configuration of the assistive technology.

The non-linear relationship between the quantities of time, position, velocity, and acceleration is expressed in Equation 2.1, in which the position of the athlete \( (x) \) is calculated using his/her initial position \( (x_0) \), initial velocity \( (v_0) \), and acceleration \( (a) \) over time \( (t) \).

\[
x = x_0 + v_0 t + 1/2at^2 \quad (2.1)
\]

The consequences of the differences in body capabilities between Paralympic and Olympic athletes to run a given trajectory in the fastest time possible are clearly seen in the world records. Table 2.1 shows that the fastest runs of Paralympic athletes approximate the fastest runs of Olympic athletes, but that the best Paralympic athlete is still slower compared to the best Olympic athlete. Also, the ratios between the Paralympic and the Olympic world records indicate that the Paralympic athlete has a disadvantage compared to the able-bodied athlete, especially at the start (short distances) and at longer distances.

To illustrate how the kinematic differences influence a race, the data divided into 20-meter sections in Figure 2.2 regarding Usain Bolt and other world-class sprinters show how individual characteristics of stride length and frequency are related to speed and time in the 100-meter final in the 2009 Berlin World Athletics Championships. Evaluating the kinematic aspects of prosthetic limb running helps to find, for example, the optimal posture of the athlete during running. Analyzing time trials helps to define the limitations of artificial knees and the consequences of changing the length of prosthetic limbs.

Kinematics are used not only to provide insight into these overall outcomes, but also to study the motions of the prosthetic limb (and/or non-prosthetic limb, for that matter) during the stance and swing phases. Often, kinematic characteristics of human (prosthetic) running are approached as a 2D action. This is an approximation and simplification of reality, of course. When scientists look more carefully, human action is hardly ever purely 2D or a planar action, but essentially a sequence of three-dimensional (3D) actions, especially in prosthetic (transfemoral) running. These 3D descriptions of human action are, however, more complicated both in calculation as well as in interpretation and presentation, which explains why the 2D approach is a more practical method for coaches and athletes.

The stick diagrams in Figure 2.3 represent the leg segments of athletes with lower-limb amputations during the stance and swing phases of sprinting while overcoming gravity, air resistance, and drag (Buckley, 1999). During sprinting, athletes with a disability use their sound limb in a similar way to able-bodied athletes; comparable kinematics of the sound limb hip and knee are found. In transtibial amputees during the stance, similar patterns of flexion–extension are evident in both limbs and prosthetic ankle angles are comparable to those of the sound side, resulting in an “up-on-the-toes” gait typical of able-bodied sprinting. In transfemoral amputees, however, a sprinting gait with large kinematic asymmetries between contralateral limbs is seen. The flexion–extension pattern is not found in a transfemoral amputee athlete, as a fully extended prosthetic knee is seen during this stance period, ensuring knee stability without buckling of the knee.

The kinematics of a prosthetic limb are not only influenced by the way in which it is controlled by an athlete but also by its design, inertial properties, weight, length, material, and type of knee joint, among other things. By changing prosthetic components, for example the extension-aiding springs, knee extension stops, or elastic and hydraulic controllers, the flexion–extension pattern during
Table 2.1 World record 2014 in Paralympic and Olympic track athletics.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Time</th>
<th>Ratio*</th>
<th>Paralympic/Olympic</th>
<th>Name</th>
<th>Class**</th>
<th>Nationality</th>
<th>Date</th>
<th>Event location</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m</td>
<td>10.57 (+1.9 m/s)</td>
<td>1.103</td>
<td>Alan Fontes Cardoso Oliveira</td>
<td>T43</td>
<td>Brazil</td>
<td>28 July 2013</td>
<td>Anniversary Games London, Great Britain</td>
<td></td>
</tr>
<tr>
<td>100 m</td>
<td>9.58 (+0.9 m/s)</td>
<td></td>
<td>Usain Bolt</td>
<td>–</td>
<td>Jamaica</td>
<td>16 August 2009</td>
<td>World Championships Berlin, Germany</td>
<td></td>
</tr>
<tr>
<td>200 m</td>
<td>20.66</td>
<td>1.077</td>
<td>Alan Fontes Cardoso Oliveira</td>
<td>T43</td>
<td>Brazil</td>
<td>21 July 2013</td>
<td>IPC World Championships Lyon, France</td>
<td></td>
</tr>
<tr>
<td>200 m</td>
<td>19.19 (−0.3 m/s)</td>
<td></td>
<td>Usain Bolt</td>
<td>–</td>
<td>Jamaica</td>
<td>20 August 2009</td>
<td>World Championships Berlin, Germany</td>
<td></td>
</tr>
<tr>
<td>400 m</td>
<td>45.39</td>
<td>1.051</td>
<td>Oscar Pistorius</td>
<td>T43</td>
<td>South Africa</td>
<td>28 August 2011</td>
<td>World Championships in Athletics Daegu, South Korea</td>
<td></td>
</tr>
<tr>
<td>400 m</td>
<td>43.18</td>
<td></td>
<td>Michael Johnson</td>
<td>–</td>
<td>United States</td>
<td>26 August 1999</td>
<td>World Championships Seville, Spain</td>
<td></td>
</tr>
<tr>
<td>1500 m</td>
<td>4:33:46</td>
<td>1.327</td>
<td>James R. Ortiz</td>
<td>T44</td>
<td>United States</td>
<td>18 April 2013</td>
<td>Lawrence, Kansas, United States</td>
<td></td>
</tr>
<tr>
<td>1500 m</td>
<td>3:26:00</td>
<td></td>
<td>Hicham El Guerrouj</td>
<td>–</td>
<td>Morocco</td>
<td>14 July 1998</td>
<td>Golden League Gala, Rome, Italy</td>
<td></td>
</tr>
</tbody>
</table>

*The ratios between the Paralympic and the Olympic world records indicate that the Paralympic athlete has a disadvantage compared to the able-bodied athlete, especially in the start and at longer distances. Therefore, it is not surprising that Oscar Pistorius chose the 400 m in which to participate in the London Olympic Games.

**In this competition, Paralympic athletes compete against each other in the lower limb deficiencies, sport classes T42–44. Although the absence of propelling calf muscle forces in the two prosthetic limbs hinders the T43 athlete during the start of the race, the characteristics of the prosthetic components compensate for this shortcoming during the second part of the sprint, in which the cadence of the limbs becomes more in line with the higher velocity, making the T43 athlete typically faster than the T44 athlete on a sound limb and only one prosthetic limb during part two. However, not only are the characteristics of the assistive device decisive for the final outcome, more importantly physical fitness (for example aerobic capacity in endurance), anthropometry, skills, and talent will determine the final result.


stance and swing can be optimized. There is a multitude of knee-joint and ankle/foot technologies, with selected choices affecting performance in an individual athlete. Compared to single-axis knees, multi-bar linkage knees provide better ankle-joint trajectories during the swing phase and more stability during the stance phase. Also, a four-bar linkage knee can provide greater toe clearance (0.01–0.03 meters) with less knee flexion during the swing phase in gait at the time of minimum toe clearance compared to the single-axis joint (Gard et al., 1996).

To influence the trajectory of the prosthetic limb during the swing phase, the athlete can use two strategies; namely, a ground friction strategy and a hip muscle strategy. The ground friction strategy helps flex the knee at the end of the stance phase. A flexed knee reduces the length of the prosthetic limb, which helps swing the limb forward with a higher angular velocity during the swing phase and increases ground clearance. By pushing the forefoot forward into the ground at the end of the stance phase, a backward-oriented ground reaction force is produced that helps to create a flexion moment on the knee, buckling the knee (see Figure 2.4, right panel). When a prosthetic foot is lifted off the ground too early, knee flexion becomes more difficult. Knee flexion during the swing phase can also be reached by using the hip muscle strategy. Because of the inertial properties of the lower part of the prosthetic limb, active hip flexion results in flexion of the knee. When larger hip torque is applied, the prosthetic foot moves relatively more upward and less forward (see Figure 2.4, left panel). When the hip is not flexing fast enough and the thigh is moving too slowly,
extension-aiding springs in a prosthetic knee may prevent flexion of the knee.

The consequences of the aforementioned biomechanical quantities, torques, and friction are studied with kinetics principles. Kinetics is a subdiscipline of classic mechanics that is concerned with the relationship between the motion of bodies and its causes – namely, forces and torques – and subsequently their effects on work, energy, and power. To determine the magnitude and orientation of forces and torques that cause the translational and rotational motions, detailed electromechanical instrumentation is required, which is in essence based on strain gauge technology. Often 3D commercial off-the-shelf measurement technology can be used, for example force plates or force sensors (www.amti.com; www.ati.com; www.kistler.com). Such technology is also available in bicycle/wheel-mounted technology that allows ambulant measurement of force/torque and speed, and power production over time.

**Coach’s Corner**

Biomechanical equations show the relationship between cause and effect of forces, motions, and energy transfer. The ground reaction force represents the combined effect of forces acting in and on an athlete’s body, making this external force essential during performance evaluation.

In biomechanics, Newton’s second law (the “Principia,” in *Philosophiae Naturalis, Principia*
Figure 2.3  2D Kinematic differences between prosthetic (pros) and sound limb sprinting, for transtibial and transfemoral athletes, showing angular displacement (degrees) and the maximum angular velocities (rad/sec) in between. Individuals wore a prosthesis with a “J-shaped” carbon fiber leaf spring that deforms during loading, resulting in controlled dorsiflexion as the shank rotates forward over the planted foot and in turn allows flexion at the knee. The patterns of dorsiflexion and plantar flexion achieved on the prosthesis show similarities to that of the sound limb in transtibial athletes. In transfemoral athletes the resultant instantaneous ground reaction force vector stabilizes the fully extended knee during the impact-absorbing phase of stance. FS: foot strike; TO: toe-off; A: ankle; K: knee; H: hip; fl: flexion; ext: extension; dfl: dorsiflexion; pfl: plantar flexion. Source: Buckley 1999. Reproduced with permission of Elsevier.
Chapter 2

Figure 2.4  Left panel: The influence of various hip flexion and extension torques applied to a mathematical model simulating swing of a prosthetic limb. The numbers in the graph represent the applied hip torques and the end position of the ankle after 0.2 s of simulation. The stick figures represent the end positions at the various values of the hip moment (flexion). The prosthetic foot is not shown in the figure for clarity reasons. Notice how the foot moves relatively more upward when larger hip flexion torques are applied. Right panel: The influence of ground friction on the prosthetic limb trajectory of a model with (A) and without (B, dashed line) static ground friction (hip torque: 100 Nm; duration: 0.2 s). The prosthetic foot is only shown in situation A. In situation B the foot is not shown for clarity reasons. Notice how the trajectory of the ankle changes when the ground friction is used to flex the knee. Source: Van Keeken 2012. Reproduced with permission of Elsevier.

Mathematica, first published in 1687), one of the basic principles for understanding changes in velocity over time is acceleration. These accelerations (a) are related to the force (F), for example muscle force or reaction force, which is applied to the object; for example, the prosthetic limb and its mass (m) as defined in Equation 2.2. This force causes an object to accelerate in a specific direction. The vector sum of all the forces (F) on an object is equal to the mass (m) of that object multiplied by the acceleration vector (a) of the object:

$$\sum \vec{F} = m \vec{a} \, (N) \quad (2.2)$$

This force equation contains linear components, informing about the linear human motions. The angular acceleration (α) relates linearly to the moment of inertia (I), a body’s resistance against rotation, described by a torque equation, as illustrated in Equation 2.3.

$$\sum \vec{M} = I \vec{\alpha} \, (Nm) \quad (2.3)$$

The linear and angular motions are the result of the forces exerted on an application point, and seldom occur separately. When a force is applied in a direction straight through the center of mass of an object that is hanging freely in space, the object moves linearly (see Figure 2.5). However, when the object is

Figure 2.5  Linear and angular motions are the result of the forces exerted on an application point. A translation occurs when a force is applied in a direction directly through the center of mass (F_{lin}). If the force is not through this point (F_{ang}), a rotation of the object occurs.
not hanging freely but makes contact with its environment (e.g., through its connecting segments), or when a force is not applied in the direction of the center of mass, the object also starts rotating when the force is applied.

Next to the internal muscle forces, an important external force, used by an athlete to move or stabilize the body and its segments, is the ground reaction force (GRF). The GRF is the force exerted by the ground in an opposite direction on a body in contact with it. An athlete who is standing on the ground or floor produces a force downward because of gravity and muscle activation, and in a horizontal direction because of muscle activation around the joints and inertial properties of body segments. Following Newton’s third law, the resulting force generates a ground reaction force in an equal but opposite direction, presuming that the athlete does not sink into the ground or slip over. This GRF represents the combined effect of forces acting in and on an athlete’s body, making the GRF, measured by the scientist with force plates, very interesting for studies. Although this result does not give exact information on how forces influence all single joints, because of this combination the GRF provides the coach and athlete with indirect information about how the athlete used muscle forces to manipulate the GRF’s direction and magnitude.

Depending on the sports research question, the GRF, like any other force, has the characteristics of a vector and thus can be split into several parts: the direction of the force (line of action), the size of the force (magnitude), the origin of the force, and the center of pressure (CoP). The CoP, which is the mean position of all forces that are generated during contact between the athlete’s foot and the ground, can be used, for example, to determine the stability of the GRF; the magnitude and the line of action provide information about propulsion.

The GRF patterns during running with a dedicated prosthetic limb differ considerably compared to a normal gait with a conventional prosthetic limb. In Figure 2.6, representing the vertical component of the GRF, only one single hump is seen during running instead of the double hump that is seen during a prosthetic gait. These two humps are associated with arrest of the downward motion of the center of mass (CoM) as the foot impacts the ground and with the second hump being the action of “push-off” as the body is propelled upward and forward. The CoM is a virtual point positioned at the average location of all segment masses, which is used often during biomechanical analyses. In a stance, in the frontal view, this point is located in the body roughly around the navel; its exact local position changes because of the relative motion of the limb segments with respect to each other. During gait this CoM also moves globally with respect to the environment, during for example flexion and extension of the knee and ankle, which causes the two humps.

In running, the non-amputee sprinter who can apply the greatest forces in the correct direction to the ground will be the winner. Because a conventional prosthetic limb lacks active components, only possessing passive mechanical and elastic components, this results in a single hump, limiting the ability of amputee sprinters to achieve speeds that are comparable to the top speeds of non-amputee sprinters. Dedicated sports-specific prostheses, J- or C-shaped carbon fiber prostheses, compensate for the lack of active components by storing energy during the landing and returning a part of this energy during the push-off. Each time body weight moves over this flexible prosthesis, the foot compresses and energy is stored. As body weight shifts off the foot, the prosthesis regains its original
shape, returning energy as it decompresses. Lower-
stance vertical forces of 9–23% on modern pro-
thetic limbs compared to intact limbs have been
reported (Weyland et al., 2009; Grabowski et al.,
2010).

The reaction forces produce pressure and stress
via the socket on the stump that might endan-
ger the integrity of the stump. With liners, energy-
absorbing heels, and shock-absorbing pylons, the
impact of these forces can be reduced. However,
it should be taken into account that an adequate
function of the socket stump interface is essen-
tial for good sports performance and for continued
good health of the athlete, and that energy that is
absorbed cannot be used for propulsion of the ath-
lete, as it decreases the effect of the GRF.

To compensate for the downward motion of
the CoM, as a consequence of the lack of verti-
cal upward propulsion in the prosthetic limb, ath-
letes have to produce extra vertical propulsion dur-
ing other phases of running to maintain their CoM
at a sufficient height. This compensation is mainly
seen at the beginning of the stance phase with the
intact limb. However, this is not the only compen-
sation strategy that is used to counterbalance this
shortcoming. Also, fast contralateral arm motions
help to overcome the lack of propulsive force in
the prosthetic limb. The asymmetrical arm swing
forward and upward increases the vertical ground
reaction force under the prosthetic limb, resulting
in more propulsion. A simple test of the effect of
a more extreme arm swing on the vertical ground
reaction force can be experimented with when one
stands on a balance scale while forcefully swinging
one of two arms upward, like in a sprint. GRF data
show that this increase in reaction force magnitude
helps overcome losses in active force production
in the prosthetic limb, making striving for symme-
try with the arms during a sprint not such a good
idea.

In the human body, the forces around the joints
produce the angular motions of the limbs. The
direction of the moment of force around a joint is
related to the vector (r) toward the center of rota-
tion of the joint and the force (F), as shown in Equa-
tion 2.4.

\[ \mathbf{M} = \mathbf{r} \times \mathbf{F} \text{ (Nm)} \] (2.4)

A distinction can be made between internal and
external moments of force. All moments of force
that are produced inside the body are called inter-
nal moments of force. Not only do muscle contrac-
tions contribute to the internal moments of force,
ligaments and bones do also. Depending on the ori-
gin and insertion of muscles relative to the joint
position, muscles are partly responsible for these
angular motions, resulting in, for example, a flex-
ion or extension moment. In the anatomical knee,
the quadriceps muscle generates a knee extension
moment around the knee joint, while the ham-
strings generate a knee flexion moment around this
joint.

The moments of force that are the result of con-
tact with objects outside the body are called the
external moments of force. It is not only that these
objects are tools or opponents, the reaction force of
the ground or floor also contributes to the external
moments of force. These external reaction forces
further influence the net moment of force around
the joint. Depending on the origin of the GRF, the
CoP, and the orientation and magnitude of the GRF,
this force produces a moment of force around the
joints. For example, when the line of action of the
GRF is in front of the center of rotation of a pro-
thetic knee, an extension moment is created that
can be used to lock the knee passively, to compen-
sate for the absence of active knee extensors (see
Figure 2.7).

Because of the absence of muscles in a prosthetic
knee, external forces and their moments of force
have an important role in prosthetic knee stabil-
ity. As stated previously, the moment of force is
related to the point of application of the force and
the position of the center of rotation of the joint.
In single-axis joints, this center of rotation is fixed
in the center of the joint. However, many mod-
ern prosthetic knees do not have these single-axis
joints, but consist of multiple linkages and axis

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**Coach’s Corner**

Simplifying the multi-segmented human body to a single center of
mass point reduces the complexity of the biomechanical analysis.
All generated forces have an effect based on their position and
orientation relative to this point.
An extension moment created to passively lock a prosthetic knee to compensate for the absence of active knee extensors; the line of action of the ground reaction force is in front of the center of rotation of a prosthetic knee.

 joints, which result in an instantaneous center of rotation. An instantaneous center of rotation travels over a certain path relative to the segments and is dependent on the angle between the segments. In a four-bar linkage joint, the instantaneous center of rotation is located on a path around the artificial knee at the intersection of two lines through the grounded links (see Figure 2.8). The shape of the instantaneous center of rotation trajectory depends on the length and position of the grounded or connecting links of the artificial knee-joint system. By varying these two factors, the shape of the trajectory can be adjusted so that the knee joint can provide more or less stability during the stance phase or change the trajectory and velocity of the lower part of the prosthetic limb in the swing phase, making it easier to move the lower part of the limb forward with more ground clearance. Choosing the position of the center of rotation in the joint wisely helps to compensate for the absence of active muscle control.

Figure 2.7 An extension moment created to passively lock a prosthetic knee to compensate for the absence of active knee extensors; the line of action of the ground reaction force is in front of the center of rotation of a prosthetic knee.

Coach’s Corner

An apparently simple rotation around a joint is actually a complex combination of internal and external moments of forces. The net moment, the combined rotational effect of all forces, gives information about the resulting effect on the joint. However, it should be taken into account that the rotational effect depends on the orientation, magnitude, and point of application relative to the joint, and therefore does not provide information about individual muscles.

The net moment of force, which is reported frequently in scientific papers, is the sum of the internal and external moments of force, and provides information about the angular motion that is being studied. However, it should be borne in mind that this net moment of force does not offer information about the actual moments of force that are produced by the agonist and antagonist muscles around the joints, or other passive (joint) structures, as their contributions are summed. When both muscle groups produce the same moment of force but in opposite directions, the net moment is equal to zero. This co-contraction of antagonists is often viewed as being inefficient. Detailed muscle activity patterns over time can be determined using electromyography. Muscle activity is, however, not identical to muscle force. While a clear view on internal forces will allow a better orientation on the potential injurious elements of a given motor action or the impact of assistive technology in (repeated) movements, this is a more complex level of biomechanics that involves modeling.

To produce muscle forces, energy (E) is needed, which in the human body can be distinguished in
several types: mechanical energy, thermal energy, chemical energy, and elastic energy. The amount of energy depends on the direction and magnitude of the force and the duration of the force that is applied.

Under steady-state conditions, given the physiological cost of work (W), the product of a force (F) acting on an object, and the displacement vector (s) or torque (M) along the angle of displacement, the object travels as a result of that force (see Equation 2.5), and the energy cost of that work for the human system can be estimated quite accurately by the measurement of oxygen consumption. However, a problem arises when predicting the mechanical efficiency of mechanical work. Simultaneous measurement of force, weight, and distance covered, using force plates, accelerometers, 3D position data-registration systems, and video, enables scientists to investigate the amount of mechanical work using mathematical models. However, it should be taken into account that some of the muscles of the body are performing positive work while others perform negative work, which makes them both energy consumers, but not equally so; the physiological cost of positive work is much more than that of negative work. Although the evaluation of mechanical work has some limitations, this mathematical method provides coaches with relevant information about athletes’ performances.

\[
W = \vec{z} \cdot \vec{F} \quad (2.5)
\]

The mechanical energy \(E_{\text{mech}}\), Equation 2.6), which is the sum of, and can therefore be divided into, potential energy \(E_{\text{pot}}\) and kinetic energy \(E_{\text{kin}}\), helps us to understand the relationship between the position and the motion of an athlete. Using this method, it is possible to calculate the total work (positive and negative) performed by an athlete at different running speeds and/or with different prosthetic components. The athlete’s CoM position during a sprint provides coaches with information about how, for example, prosthetic components influence performance (i.e., in their contribution to interchanging kinetic, potential, and elastic energies). Potential energy is the energy that is by virtue of the relative position (h) of an object within a physical system. When the CoM is at a relative height, the potential energy is equal to the object’s mass (m) multiplied by the gravity constant (g) and the relative height (h); see Equation 2.7.

\[
E_{\text{mech}} = E_{\text{elastic}} + E_{\text{kin}} + E_{\text{pot}} \quad (2.6)
\]

\[
E_{\text{pot}} = mgh \quad (2.7)
\]

Kinetic energy \(E_{\text{kin}}\) is the energy of an object in accordance with its linear (see Equation 2.8) and angular motion \(v, \omega\), Equation 2.9). Kinetic energy is defined as the work needed to accelerate a body from rest to its current velocity. Having gained this energy during its acceleration, the body maintains this kinetic energy unless something takes it away, for example frictional forces. Negative work of the same magnitude would be required to return the body to a state of rest from that velocity.

\[
E_{\text{kin lin}} = 1/2mv^2 \quad (2.8)
\]

\[
E_{\text{kin ang}} = 1/2mr^2\omega^2 = 1/2I\omega^2 \quad (2.9)
\]

Changes in kinetic energy are the result of forces that cause the object to move in a different direction or with a different velocity. These forces are produced by the athlete’s muscles or are the consequences of interaction with other objects or the environment in which the athlete moves, for example when the prosthetic foot is placed on the ground. The total work by the athlete can then be calculated through the potential, kinetic, and rotational energy states (see Equation 2.10).

\[
W = E_{\text{pot}} + E_{\text{kin lin}} + E_{\text{kin ang}} \quad (2.10)
\]

When evaluating the oscillation of the athlete’s CoM during sprinting, negative and positive work are found respectively at the beginning of the stance phase and at the end of the stance phase during the control of the downward motion of the CoM after heel strike and during the upward motion of the CoM before the push-off. The influence of the absence of an active component in the prosthetic limb can be estimated using these equations in combination with the kinetic quantity power (P), which is the rate (t) at which work (W) is performed over time (see Equation 2.11).

\[
P = W/t(W \text{ or } J\text{s}^{-1}) \quad (2.11)
\]

These power equations of the total system or at joint level, where joint power is the product of the
joint moment and the joint angular velocity, help to estimate the magnitude of the total concentric or eccentric actions, which can be of help in evaluating prosthetic limb joint components and muscle force training. Calculating the mechanical work and the rate at which it changes tells the coach that the current running prosthesis does not match the human foot and knee in their mechanical behavior. Although the weight of the components of the modern prosthesis is less than that of the human counterparts, the absence of the active components to produce work is the reason that a prosthetic limb cannot match a human limb. The absence of muscles limits the propulsive power generation and the related work and velocity. The modern carbon fiber prostheses, with optimized stiffness and shape, may have an advantage over a human limb, since they can store energy in their elastic components that can return work, and seem to allow Paralympic athletes to attain the same energy costs as Olympic athletes during running. However, changing the stiffness of a prosthetic component influences the work that is returned at the end of the stance phase, and also changes the energy losses because of material deformation during the stance phase.

Coach's Corner

Appropriate alignment makes the difference between flexion and extension of a joint during the critical phases of a motion. Based on objective biomechanical data, the effect of prosthetic alignment can be evaluated and modified for improved athletic performance.

Since forces and their point of application are important for the motion of body parts (see Equations 2.2 and 2.4), it is of the utmost importance that the prosthetic limb is aligned correctly; adequate alignment of sports prostheses is necessary for both performance and comfort. Although the shape of the stump changes under a load, affecting the length of the moment arm (see Equation 2.4), an optimal alignment should be pursued. Adequate alignment reduces the pressure and stress on the stump and facilitates control over the joints in the prosthetic limb.

When the direction of the line of action of a force is inadequate, athletes using a badly aligned prosthetic limb can experience several problems. As mentioned before, the ground reaction force helps in extending and flexing the knee during the stance phase. If the line of action is incorrect, the knee might buckle too soon when a flexion moment occurs, or it might be impossible to flex without a great deal of effort, or work, to overcome an external extension moment. Also, when a prosthetic limb is badly aligned, pressure and stress on the stump may occur, resulting in discomfort or worse (e.g., stump ulcers).

Static alignment using the Laser-Assisted Static Alignment Reference (LASAR) might help find a good alignment, or at least a standard against which alignment can be adjusted. However, dynamic alignment during sports activities might be different than static alignment and the LASAR technique might therefore not be optimal. Individualized multi-segmental mathematical models can help find the optimal alignment of the prosthetic limb for the Paralympic athlete.

Mathematical models

To understand how forces and torques influence the motion of bodies, simulating biomechanical elements and principles with mathematical models can be of great help.

Mathematical models enable scientists, coaches, and athletes to study the causes of the motions of the Paralympic athletes and their equipment. Phenomena that occur during sports activities can be analyzed in a simplified setting using mathematical models that help to make predictions about the causes of these phenomena. Depending on the sports research question, reducing the real world into a conceptual world helps to focus on that research question, what is already known, and perhaps what has to be assumed. Based on observations and (motion) measurements, perhaps, but not exclusively, in a laboratory setting and by making use of models, predictions can be made about these phenomena, either to describe or explain what is happening or to tell in advance what will happen when the posture is changed or when the design of the equipment is adjusted. It should be noticed that there is not just one mathematical model that can help explain every phenomenon that occurs.
Because of the simplification, some assumptions that have to be included in the models are certainly not always valid for the human body. Nonetheless, they should always be very useful approximations in practice. In the predicting part, the outcome of the model always has to be compared with the phenomena in the real world to validate and verify the model, or to suggest reasons that the model is inadequate (see Figure 2.9). To study static or dynamic sports situations, free body diagrams and kinetic diagrams are used to visualize motion components and interaction with the surroundings (see Figure 2.10).

In these models we assume that forces are the driving part of the model. To understand how forces act on body parts and affect their motions, inverse and forward dynamics models are used. In the inverse dynamics process, measurement data of body part motions are used to determine, for example, how forces of contracting muscle were likely applied during the motion of the athlete. During the opposite process, called forward dynamics, forces are used as input for the model to predict the motions of the athlete. The process can be employed to study the influence of training on, for example, timing of muscle contraction, to predict how this change will influence the motion of the athlete. The forward dynamics process allows us to study the results of changes in training or mechanical design, without actual training or building the assistive devices in the real world. This possibility makes this process very important for the development of training programs and equipment in athletic amputee running.

To use these models during static and dynamic analysis, several steps have to be taken. In a
sufficiently simplified model containing a body of interest, all necessary known and unknown forces should be defined in an algorithm containing a series of mathematical equations and/or should be measured. During the analysis of these motions and forces, the laws of physics should be taken into account. In an applied Paralympic sports setting, such analysis can only be conducted by a well-trained sports scientist.

Kinematics and kinetics of wheelchair sports

An important and productive biomechanical pathway to studying wheeled sports and mobility over the past decades has been power balance, where power flow, work production and force application, and kinematics of technique are melded together with aerobic and anaerobic power production, energy cost, and mechanical efficiency, which are measures taken from exercise physiology. This model indeed brings biomechanical applications and their underlying physiological context together and provides a practical playing field for interpreting and optimizing Paralympic sports performance from a biomechanical perspective, as is exemplified by wheeled sports performance.

Coach’s Corner

Sports performance is the result of multiple factors, depending on the environment, the equipment, and the athlete’s characteristics. The power balance is a useful tool to gain insights into the relation between the athlete’s energy input and the resulting power output.

Power balance model

When athletes move at a given speed (v) with their wheelchair or handcycle, they encounter several resistive forces (N): rolling friction ($F_{\text{roll}}$), air resistance ($F_{\text{air}}$), gravitational effects when going up/down a slope ($mg \cdot \sin \alpha$), and internal friction ($F_{\text{int}}$). The product of the sum of these drag forces with the velocity of the athlete equals the power output (W) that must be produced to maintain that velocity. The power balance can be expressed by Equation 2.12:

$$PO = (\vec{F}_{\text{roll}} + \vec{F}_{\text{air}} + \vec{F}_{\text{int}} + m \cdot g \cdot \sin \alpha + m \cdot \vec{a}) \cdot \vec{v}(W)$$

(2.12)

where PO is the external power output in watts (W), $a$ is the acceleration of the system, $m$ is the mass of the athlete plus wheelchair or handcycle, and $\alpha$ is the angle of the slope or inclination. The external power output (PO) is produced by the athlete and is necessary to overcome all the drag forces. When more external PO is generated (through the use of more muscle force and power by the athlete) than is needed to overcome the actual drag forces at a certain speed, there will be acceleration (a). The magnitude of actual acceleration is dependent on the mass of the athlete and the wheelchair or handcycle ($m \cdot a$). Also, the extra power output can be used to overcome a slope ($m \cdot g \cdot \sin \alpha$) or more head wind ($F_{\text{air}}$). On the other hand, when the athlete's internal power output does not increase, negotiating a slope will lead to a slowing down.

Rolling resistance

Rolling resistance is dependent on the floor surface, but also on the characteristics of the wheels (size) and tires (profile, pressure). The magnitude of the rolling resistance is related to the amount of deformation of tire and floor surface. This deformation is dependent on tire pressure, tread, and profile, but also on wheel diameter and wheel alignment. Wheel toe-in or toe-out has a considerable effect on rolling resistance. The effect of camber on rolling resistance is not so clear, however. One study showed an increase in rolling friction with an increase in camber (Mason et al., 2011). The position of the center of mass is especially important for wheelchair racing. The position of the seat in relation to the rear axle should be such that the chair is stable to avoid tipping over backward, but not so far forward as to put too much weight on the smaller front wheel, which increases the rolling friction. For an overview of factors that have an effect on the rolling friction, see Table 2.2.

The effect of changing tire pressure or camber on the rolling friction can be determined by a drag
Table 2.2  Factors that can affect the rolling friction.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Effects on rolling friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Wheelchair mass ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Tire pressure ↓</td>
<td>↑</td>
</tr>
<tr>
<td>Wheel size ↓</td>
<td>↑</td>
</tr>
<tr>
<td>Hardness floor ↓</td>
<td>↑</td>
</tr>
<tr>
<td>Camber angle ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Toe-in/toe-out ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Castor shimmy ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Center of mass over large rear wheel axis ↓</td>
<td>↓</td>
</tr>
<tr>
<td>Maintenance ↓</td>
<td>↑</td>
</tr>
</tbody>
</table>


test or a coast-down test. A drag test can be performed on a treadmill with the athlete in his or her wheelchair or handbike (see Figure 2.11). The wheelchair is connected to a force transducer with a rope. The rope is positioned parallel to the surface of the belt and attached to the vehicle as close as possible to the vehicle user’s center of gravity. During the drag test, the athlete sits passively in the wheelchair or handbike. The treadmill belt is set at a fixed velocity and the slope is increased during the test. After the test, the drag force can be calculated per inclination with the outcomes of the force transducer. Thereafter, the power output can be calculated by multiplying the drag force by the belt velocity during the test. However, it should be kept in mind that drag tests and coast-down tests can measure changes in camber or tire pressure, but are not taking into account the interface dynamics. During these tests the athlete is sitting still, in contrast to the sporting activity.

A coast-down test can also give an indication of the rolling resistance. For this, the wheelchair or handbike is positioned on a standardized slope (slope angle and length) and can be released to coast down the slope in a straight line (arms are used to steer, not to propel) over a fixed and known distance. The time to cover the distance between start and finish is measured using a stopwatch or timing gates. The time for the distance traveled is indicative for rolling (and internal) friction. When a standardized slope is not available, athletes can be asked to accelerate up to a certain speed and then coast down in a sport-relevant position. The deceleration is then registered.

Air resistance

The second important factor in the power balance equation is air resistance. In wheelchair racing and handcycling, this is a very important source of energy loss. Air resistance force is proportional to the square of the actual wind or air velocity with respect to the athlete. Therefore, air resistance is of minor importance at low speeds, but at high speeds and/or wind velocities it will be the most important source of resistance, and much larger than rolling resistance (which is independent of speed). The effect of air resistance on power output can be shown by the following example. At a slow speed (1 m/s) the air drag will be below 1 Newton (N), while at 5 m/s the drag force due to air resistance can be already 14 N. So at 5 m/s the average power output to overcome only the air resistance can be already 14 N. So at 5 m/s the average power output to overcome only the air resistance is (5 m/s × 14 N =) 70W (as opposed to 1W at 1 m/s in the initial situation). Besides the velocity, the frontal plane area (that is, the plane or total surface that one can measure from a photograph from the front of the athlete–wheelchair combination) is also very important in this respect (see Figure 2.12). The larger the frontal plane, the larger the air drag.
Figure 2.12  A wind tunnel measurement, where air drag on the athlete is produced through artificial wind, while its effects in terms of drag force are measured using an instrumented force platform. Effects on air drag of frontal plane area, sitting posture, clothing, helmet forms etc. can thus be studied individually.

With the help of a biomechanical model using the power balance, Groen et al. (2010) evaluated both rolling resistance and air resistance in elite handcyclists who were propelling their handcycles – instrumented with a Powertap – at different speeds on an indoor track, as illustrated in Figure 2.14.

Internal friction

Energy losses within the wheelchair or handcycle can be caused by bearing friction around the wheel axles, and for the wheelchair also in the wheel suspension of the castor wheels. However, bearing friction is normally very small when the bearings are well maintained and lubricated. Another form of internal friction can be deformation of the frame during the force exertion in the push phase. This type of friction will also be very low, especially since the material of elite sports wheelchairs and handcycles is made stiffer by using high-tech materials (such as carbon).

Slope and acceleration

Although body mass and wheelchair or handcycle mass have a small effect on rolling resistance,
they have a considerable effect when riding up a slope or when accelerating. The potential to accelerate is inversely related to the total mass at a given power output (i.e., acceleration will be slower when the mass of the system is larger). The mass is also linearly related to the power output when ascending a slope. Of course, this extra investment will be returned partially during descents, but will still lead to higher losses because of the higher velocity when going downhill.

Figure 2.14 Coasting speed (v; x in equation) and external power output (PO; y in equation) as measured with a Powertap during handcycling on a cycling oval. The equation models the terms for the frictional losses due to internal and rolling friction (2.90x) and air drag (0.20x^3) at a given speed (x). Source: Groen 2010. Reproduced with permission of Taylor & Francis.
The mass of the wheelchair can be influenced by choosing lightweight materials. However, this relative contribution must be weighed in light of the athlete’s (over)weight. The added effect of mass (m) on the drag force while propelling up a slope (α) can also be determined with the earlier described drag test on a treadmill, but also calculated when the slope is known (m.g.sin(α)). The acceleration due to gravity (g ~ 10 m.s\(^{-2}\)) times the sinus of the slope angle times mass (kg) creates a force that essentially decelerates the wheelchair–athlete combination when going up a slope or accelerates it when going down a slope.

**Power production**

To overcome all the drag force, the athlete has to produce external PO. As already stated, the external PO is dependent on the velocity and the resistance. However, it can also be calculated as the rate at which work is done (Equation 2.13). For wheelchair propulsion or handcycling, that means the amount of work done per push or per cycle respectively. For wheelchair propulsion, there is power production during the push phase when the hands are in contact with the rims (see Figure 2.15). The athlete can vary the amount of work done per push as well as the push frequency while maintaining the same power output (see Figure 2.16).

\[
PO = \text{Work per cycle} \times \text{frequency (W)} \quad (2.13)
\]

In contrast, in handcycling the hands are continuously attached to the pedals and therefore power can be generated during the whole cycle (see Figure 2.15). In handcycling, the same average power output can only be delivered with a higher push frequency when the gears are set differently so that the amount of work done per cycle is less.

How much power can be generated by the athlete is dependent on many factors. First, it is dependent on the athlete’s attributes. There are some characteristics that cannot be changed, such as anthropometrics, gender, age, and impairment, while others can improve due to practice, such as physical capacity (strength, aerobic capacity, anaerobic capacity, flexibility) and skill. Secondly, more power can also be generated when the wheelchair or handcycle is adjusted perfectly to the athlete, such as seat height and distance between shoulder and crank (see Figure 2.17).

A good measure to evaluate the fit of the wheelchair or handcycle to the athlete is the efficiency. The gross mechanical efficiency (see Equation 2.14) is defined as the ratio between externally produced power output, which can be measured by a drag test or by power-measuring systems in the crank or wheel, and internally liberated energy, which is the predicted oxygen cost under submaximal, physiological steady-state conditions (En).

\[
ME = \left(\frac{PO}{En}\right) \times 100(\%) \quad (2.14)
\]
Figure 2.16  The three graphs represent the produced effective torque around the wheel axis by the same novice person who is propelling the wheelchair at the same velocity and power output on a motor-driven treadmill over 3 blocks of 4 min, using a clearly different push frequency and work per cycle, in the early course of learning handrim propulsion over time. Source: Vegter 2013. Reproduced with permission of IEEE.

Figure 2.17  Handcycle–user combination in a drag test on a treadmill. The user is passively seated in the chair and controls the steering. The combination is connected with a rope to a strain gauge at the front that is fixed to the treadmill frame. This gauge measures the drag force due to rolling and internal friction as well as the gravity effects of the slope of the treadmill. Reproduced with permission of Annet Dallmeijer.
This mechanical efficiency for arm exercise is normally lower than for leg exercise due to the smaller muscle mass involved. Furthermore, the efficiency is often also lower for wheelchair propulsion compared to handcycling. This might be due to the more complex movement pattern during wheelchair propulsion and the necessary coupling and decoupling of the hands to the rim compared to handcycling. Due to the higher mechanical efficiency in handcycling, the peak external power output that can be attained in handcycling is normally higher than that in wheelchair propulsion.

The oxygen uptake can be measured by a metabolic cart during exercise tests or, since mobile systems exist, in the field (see Figure 2.18).

However, standardized testing is necessary for determining the gross mechanical efficiency, and therefore these tests are often performed in a laboratory setting, with the wheelchair or handbike on a roller or treadmill or with an armcrank or wheelchair ergometer (see Figure 2.19). The PO when riding on a treadmill can be assessed with a drag test. Some specifically built rollers are also able to measure the PO. The advantage of using the treadmill or roller is that athletes can be tested in their own wheelchair or handbike. Adjustments to the wheelchair can be evaluated in this way and the peak PO of users in their wheelchair or handbike can be assessed. This is in contrast to testing on a wheelchair or armcrank ergometer, which can be adjusted as well but always has its limitations in that regard.

### Skill and technique: Training and coaching

The overall performance of the athlete is not only dependent on physical capacity but also on wheelchair skills and propulsion technique. The acquisition of skills and propulsion technique is part of motor learning, which is defined as a change, resulting from practice and supported by coaching, in the capability to respond. It often involves improving the smoothness and accuracy of movements, and is obviously necessary for complicated movements such as wheelchair propulsion.

### Coach’s Corner

Coaches and athletes often have a great athletic intuition and eye for skill. Simple and “smart” measurement technologies may help support their ideas and provide a more objective view.

An important skill in wheelchair and handbike sports is accelerating, which is needed at the start of a sprint or race to be able to be faster away than the opponent, but also at the end of a race to beat the opponent in the last few meters. Preliminary results in wheelchair tennis have shown that the higher-ranked players had better acceleration skills. This can be measured easily by timing the split times at 2.5 m, 5 m, and 10 m during a 20-meter sprint using time gates and calculating the speed.
over each distance. More precise information about acceleration during tests, but also during games (see Figure 2.20), can be collected by using video analysis, global or local positioning systems, laser cameras, or accelerometers. In this way data trajectories during tests and games can be visualized, and data parameters like traveled distance, speed, and acceleration can be calculated.

Maneuvering is another important skill, especially in wheelchair ball sports in which the athlete has to slalom through other players. This skill can also be tested with a simple field test in

Figure 2.19  Measuring power output during a test on a roller (A), on a treadmill (B), on an armcrank ergometer (C), and using a wheelchair ergometer (D).

Figure 2.20  Visual representation of trajectories of wheelchair rugby players during half a game after tracking videos. Source: Sarro 2010. Reproduced with permission of Taylor & Francis.
which a standardized slalom test is timed. When more specific information is necessary regarding the task execution, for example whether the player is making wide or small turns (see Figure 2.21) and whether that is changing over time, then the above-mentioned measurements regarding acceleration can be used here too.

Propulsion technique, which is the way the force is applied on the handrim or pedals, is also a factor that improves with motor learning and is affected by the wheelchair or handbike configuration. Figure 2.16 shows the first 12 minutes of a new wheelchair user learning wheelchair propulsion. The force application changes due to learning, with a reduction in push frequency and an increase in work per push. Furthermore, the negative work per cycle, depicted as the filled surface below the zero, is caused by the coupling/decoupling of the hand to the rim, and that reduces over time as well.

The way in which wheelchair users apply force to the handrim (i.e., how they generate the power output) can be measured by commercially available measurement wheels (see Figure 2.22) or on a wheelchair ergometer (see Figure 2.19D), which measures the applied forces and torques in three directions.

These measurements can be accompanied by video cameras registering the movement to determine joint angles (kinematics), and by measuring muscle activity using electromyography (EMG). This combined data set not only shows the force applied to the handrim, but also how athletes apply this force to the rim in terms of, for example, trunk movement or elbow flexion and extension, and which muscles they turn on and when during the cycle. An example of which muscles are active during wheelchair racing is shown in Figure 2.23.

When the mechanical efficiency is low (i.e., the energy cost is high for the athlete during a certain task), this might be explained by the timing of muscle activity. When during a propulsion cycle flexors and extensors co-contract, more energy is needed compared to the extensors only exerting power.

Figure 2.21 Visual representation of trajectories during a wheelchair skill test, measured by an accelerometer set-up mounted on the wheelchair frame center.

Figure 2.22 Two commercially available 6 DoF (six degrees of freedom) measurement wheels: (A) SmartWheel; (B) Optipush.
Figure 2.23  Raw and normalized EMG of eight muscles during wheelchair racing. The vertical lines indicate instants of hand contact and release (solid lines) and maximum elbow height (dashed lines). Source: Chow 2001. Reproduced with permission of Wolters Kluwer Health, Inc.
output. This means that the internally liberated energy is high, but it is not all used to generate power output, so the efficiency is low. This is often seen in athletes with cerebral palsy due to spasticity, but might also be due to non-optimized adjustment of the wheelchair or handbike to the user.

Muscle activity leads to movement, which can be visualized as movement patterns or by showing precise joint angles when using kinematic measurements (see Figure 2.24). In general, the propulsion technique of more skilled athletes is characterized by long strokes, which lead to more work per cycle, a lower push frequency, and lower peak forces. These long strokes may be generated by more trunk movement and larger joint angles. However, this activity is also dependent on the impairment of the athlete: those with good trunk control are able to make longer strokes. When accelerating (i.e., when starting from a standstill in wheelchair ball sports), the trunk is often used. Thereafter, during steady-state submaximal wheeling, the trunk is often used minimally because of energetic reasons.

**Figure 2.24** With kinematics the movement pattern (of for example the hand) can be visualized (upper graphs) and specific joint angles can be calculated throughout the cycle (lower graph). Source: Tsai 2012. Reproduced with permission of Springer Science+Business Media.
Assistive technology: Athlete optimization

To enable power generation by effective force application and to maneuver easily across a competition court, optimization of the wheelchair or handbike to the athlete is of the utmost importance. This individual fine-tuning concerns not only the minimization of mechanical losses of the rolling device (i.e., air, rolling, and internal drag forces), but also the optimization of the wheelchair–user interface.

Rim radius or gear ratio

For handcycling in a mountainous terrain, different gears are chosen when compared to a flat terrain. This is more complicated in a handrim wheelchair. The handrim radius is in fact the gearing system of a wheelchair. Smaller handrims will result in a larger force and lower hand velocity at a given traveling speed. Different sports or task conditions will theoretically require different handrim diameters or gearing levels. In wheelchair track events or marathons, handrim diameter optimization may improve individual racing performance.

A study on wheelchair racing involving high velocities showed clear effects of rim diameter on physiological parameters (van der Woude et al., 1988). Cardiorespiratory stress was lower with smaller handrims. A comparison between the smallest (0.3 m) and largest handrims (0.47–0.56 m) at the highest propelling speed showed a 20–30% difference in average oxygen cost, ventilation, and heart rate. Half of the participants were not able to perform the test at the highest speed (4.2 m/s) with the largest handrim. The upper arm range of movement in the sagittal plane, the degree of upper arm “abduction,” and the degree of elbow “flexion” (reflected in the minimum elbow angle) increased rather linearly with handrim diameter. Surprisingly, the rim diameter did not have an effect on push frequency, push time, recovery time, push angle, and work per cycle. However, in this study only the rim diameter was changed; the seat position was not changed accordingly, which might have induced a larger effect.

Besides rim radius, the size of the wheels can make a difference in power generation, since larger wheels have a positive effect on rolling resistance and subsequent physiological costs. In basketball players, larger wheels improved maximal sprinting performance, while no negative effects on acceleration or maneuverability were seen. In short, optimization of wheel size and rim radius, within regulations and for a specific sports discipline, is important.

Rim shape/gloves

Force is applied from the hand to the rim, therefore the grip of the hand on the rim is critical. The rim can differ in diameter or shape and materials may differ (e.g., steel, carbon, or covered with foam; see Figure 2.25), while gloves can be used for a better grip. A study on rim configuration under

Figure 2.25  Different wheelchair handrim configurations. Source: van der Woude 2003. Reproduced with permission of Elsevier.
daily life conditions regarding speed and PO found no effects of shape and material on physiological and biomechanical measures (van der Woude et al., 2003), while a larger oval tube diameter seemed to improve gross efficiency without changes in propulsion technique (van der Linden et al., 1996). Having a better hand grip may reduce stabilization effort by the larger muscles at the elbow and shoulder. Gloves can have an effect on measures of acceleration and sprinting in wheelchair rugby athletes. However, the athlete’s own gloves performed better than new prototype gloves or general-purpose gloves, making it hard to conclude which material is more optimal.

Camber
The majority of sports wheelchairs have cambered rear wheels; that is, the wheels are fixed to the frame such that the wheels are much closer to one another at the top than at the bottom. This provides improved stability and maneuverability, and protects the hands in ball sports. Recent experiments in court athletes indicated that a larger camber angle (24°) leads to a higher PO at the same velocity, meaning that the drag force increases with camber angle. As a consequence, a higher oxygen uptake and heart rate at the same velocity are seen, which could be due to the greater ranges of motion for shoulder flexion and elbow extension during the push phase at the 24° camber angle. From field tests, it was also concluded that a camber angle of 24° had a negative effect on linear performance. In contrast, an 18° camber was suggested to be the best for both sprint and maneuverability skills (Mason et al., 2011, 2012).

Seat height and position
Seat height is an important factor regarding optimizing the wheelchair or handbike to the athlete. In daily life wheelchair conditions, an optimum seat height was found with an elbow angle of between 100° and 130° (full extension is 180°) in people with a spinal cord injury. Physical strain and mechanical efficiency were best at these seat heights, while lower seat heights were detrimental. Also, improved force application (i.e., lower forces) was necessary for the same task performance when the seat height increased (van der Woude et al., 2009). However, other studies found that a lower seat height improved the push time and push angle, although it increased the forces (Kotajarvi et al., 2004). When the seat height increased, the trunk shifted further forward and the elbow joints shifted their motion more to extension, while no changes in angular velocities were seen with a change in seat height. Although these studies were not performed in sports wheelchairs, it is clear that there is a relationship between seat height and physiological and biomechanical parameters. Optimizing seat height for individual athletes therefore seems to be very important.

Besides seat height, the fore–aft position of the seat relative to the rear wheels is important. When shifting the axle position, the mass distribution over the rear and front wheels changes and affects rolling resistance. Resistance is lower when the center of mass lies over the large rear wheels. Yet, apart from resistance, propulsion technique also changes (push frequency, push angles, forces) and should therefore be taken into account when setting seat position. In wheelchair court sports, a fifth wheel at the back prevents the athlete from tipping backward. Therefore, the center of gravity should be positioned on top of the rear wheel axle to maximize maneuverability and minimize rolling resistance. However, in wheelchair racing the position of the seat in relation to the rear axle should be balanced such that the chair is stable (not tipping backward), yet not too far forward as to put too much weight on the smaller front wheel (increasing rolling friction).

Handbike
Regarding optimizing the handbike set-up, few studies are available and those that exist are mostly focused on daily life handcycling. In handcycling, the force transfer from the user to the bike to the road occurs by using the front wheel effectively. When the center of mass is too far back, the front wheel will not have enough “grip” and will tend to slip. This is especially the case when going uphill.
Coach's Corner

To build a specific upper body work capacity, handcycling is to be preferred over handrim wheelchair training. The fully continuous motion and consecutive use of a much larger and diverse set of upper body muscles lead to much lower peak forces at the same power output.

One study investigated the handbike–user interface regarding crank position (two distances, two heights) and backrest inclination (Arnet et al., 2014). The model analysis showed that in people with a spinal cord injury, a more upright backrest position resulted in lower shoulder load compared with the most reclined position, while no difference in mechanical efficiency was seen. No differences in shoulder load or efficiency were found for the different crank positions, except for a reduction in subscapularis activity at the distant position.

Health and safety

Changes in wheelchair or handbike set-up affect not only performance, but also joint and muscle loading as well as sitting pressure or shear forces. Skin problems, or even pressure sores, can occur when the sitting position is not optimal. Pressure sores are often seen in people with a spinal cord injury. When these sores occur, it is not easy to get them cured quickly and besides the effect that they have directly on the athlete’s health status, they can also have an impact on training schedules (i.e., an inactive period for several weeks or months). Therefore, optimization of seating position and cushioning must always be done with health and safety in mind, and not only considering performance-based physiological or biomechanical outcomes.

As already stated, the activity of superficial muscles (i.e., muscles just below the surface of the skin) can be directly measured by electromyography. With this information, timing of the muscles during push and recovery phase, but also their activity relative to their maximal ability, can be determined. With these measurements it was previously established that during the push phase there is synergistic muscle activity for shoulder flexion (deltoides anterior, pectoralis major), external rotation (supraspinatus, infraspinatus), and scapular protraction (serratus anterior). During the recovery phase, shoulder extension (deltoides posterior), abduction (deltoides medialis, supraspinatus), internal rotation (subscapularis), and scapular retraction (trapezius medialis) take place. Since the (high) forces are delivered only during the push phase in wheelchair propulsion (see Figure 2.24), the muscles that are active in this phase are trained much more than the muscles that are active in the recovery phase, and an imbalance between agonists and antagonists (e.g., shoulder flexors and extensors) can occur. This imbalance can lead to injuries in the long term. Therefore, it is important for wheelchair athletes to follow a complementary and compensatory training program, outbalancing functionally different muscle groups. In contrast, the force production in handcycling is generated more evenly throughout the whole cycle due to the pushing and pulling movement (see Figure 2.24), therefore this imbalance will probably not occur and the injury risk is expected to be lower.

Biomechanical models are used to quantify the load on the musculoskeletal structures, such as the shoulder, elbow, or wrist joints. Detailed kinematic data (i.e., the location of bony landmarks during propulsion) and 3D external forces and moments applied by the hand on the handrim (wheelchair) or crank (handbike) serve as input for such an inverse dynamic model. The model can calculate glenohumeral contact force and relative muscle forces relevant for task execution. Wheelchair propulsion often leads to overuse injuries, a fact that is probably related to the high (glenohumeral) joint contact and muscle forces during the push phase, which are much lower in handcycling (see Figure 2.26). Although this figure represents daily life handcycling and wheelchair propulsion, the expectation is that due to the discontinuous movement pattern in wheelchair propulsion in contrast to handcycling, similar results will be found for athletic performance.

Individual sports performance

Testing and monitoring athletes in combination with their assistive technology (i.e., wheelchair,
handbike, or prosthesis), and under standardized but close to realistic sports conditions, is very important to help understand and optimize individual sports performance. For more than two decades, adapted running sports have benefited from human movement and sports sciences and rehabilitation-based gait laboratories all over the world. Motion-capturing and force-plate technology have evolved from gait and running science in athletes with an impairment and in patients. Prosthetic technology has evolved in this context of substantial biomechanics research.

Similar developments have more recently evolved from rehabilitation-related research on wheeled mobility, where instrumented wheels and treadmills or ergometers in combination with ambulant motion-capturing systems and metabolic units allow the careful study and monitoring of wheelchair users and athletes, both in a laboratory setting as well as in a more practical setting. Paralympic sports can benefit from these developments more than currently is the actual practice.

The set-up of the wheelchair or handbike to the user can be optimized by performing several tests with different set-ups. Furthermore, the improvement of the athlete due to training and skill acquisition can be evaluated by testing the athlete over time. This testing can be done in a simple manner by merely timing certain tasks with a stopwatch, or by taking multiple pictures to be able to see differences in sitting position between changes in the set-up or to make videos to see how someone moves in their wheelchair or handbike when changing certain aspects. These simple measurement methods can be extended by adding sophisticated laboratory methods to measure rolling resistance, force application on the rim or crank, joint angles, or oxygen uptake, to enable calculation of mechanical efficiency or to use these measurements as input for a model to investigate loading on upper body joints.

To improve sports performance by testing, it is very important to formulate the right questions and to perform tests that answer those questions.

**Coach’s Corner**

Paralympic performance will benefit from systematic monitoring and measurement, as well as collaboration with embedded scientists in the training field and during Paralympic events.

Figure 2.26  Glenohumeral contact force (calculated joint reaction force vector) during daily life handcycling (left) and wheelchair propulsion (right) (group mean and SD). Source: Arnert 2012. Reproduced with permission of Foundation of Rehabilitation Information.
Especially with the more time-consuming and complex tests described here, it is important to discuss the questions and the chosen tests (e.g., field or laboratory test), and to interpret the results thoroughly in a team including the athlete, the coach, the wheelchair or handbike specialist, and an embedded human movement scientist (with an understanding of biomechanics, ergonomics, or physiology) with adequate knowledge of the impact of impairment on performance. For easier interpretation, researchers in rehabilitation and adapted sports try to visualize results by showing combinations of force application and video (see Figure 2.27).

**Figure 2.27** The MoxieViewer, a software program to visualize force application from measurement wheels at the bottom panel (and/or EMG, joint angles) simultaneously with a 2D video of the actual performance (top panel). Source: De Groot 2014. Reproduced with permission of Foundation of Rehabilitation Information.
Critical when monitoring athletes over time is standardization of the test. The test has to be performed exactly the same way over time so that possible differences in test results are due to the aspect that has changed (i.e., camber angle or the athlete due to training) and not because the test is performed slightly differently. That is why researchers often perform tests in a laboratory setting and not in the field.

Although biomechanical outcomes may seem rather self-evident, they often are not. Both reliable and valid biomechanical data acquisition as well as interpretation require a Paralympic sports and human movement sciences background. This implies close collaboration between sports practice and sciences, and may lead to an embedded scientist being part of the sports performance team of an athlete or sports team.

**Conclusion**

Biomechanics helps to approach Paralympic sports performance from an ergonomics perspective, where apart from sports performance, potential health and safety issues must be considered. Consistent use of biomechanics principles by the coach, athlete, and sports scientist in Paralympic sports practice will help to make a difference and increase athletic (team) performance, as well as prevent overuse-related injury.

**References**


Chapter 3

Physiology

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Introduction

Humans require a continuous supply of chemical energy to maintain numerous and complex physiological functions, making the human body one of the most fascinating systems in existence. Possible acute and chronic adaptations in the human body due to increased physical activities (or the opposite, bed rest) in elite athletes are fascinating and impressive. Physiological adaptations of the human system aim to generate a steady state, also known as homeostasis, a situation in which all physiological variables are regulated toward stability dependent on the level of activity. Exercise physiology mainly deals with adaptations in the athlete’s body to reach a homeostasis of a higher quality. It is associated with an increasing capacity to supply chemical energy following systematic training. The human body extracts energy from carbohydrate and fat sources (and to some extent also from protein), which supply the energy to power all biological work. At the cellular level, exercise physiologists study adenosine triphosphate (ATP, the special carrier molecule of free energy) synthesis to power biological cell work. Many complex physiological functions can be reduced to optimize and increase the ATP supply in human cells (especially muscle cells).

At first glance, there are few fundamental differences in the physiology of Paralympic and Olympic athletes. Most of the reactions and adaptations of the human system to training interventions are similar with respect to individual characteristics and sport preferences (age, sex, sport discipline) and the training status of the athlete. This means that most of the information collected from Olympic athletes is useful for Paralympic athletes and support staff. Nevertheless, there are some important characteristics of the Paralympic athlete that should be considered for training and competition. Webborn and Van de Vliet (2012) define Paralympic athletes as competing within the following six main groups:

- Amputation or limb deficiencies
- Cerebral palsy
- Spinal cord-related impairment
- Visual impairment
- Intellectual impairment
- Range of physically impairing disorders not in the scope of the above groups (les autres)

For these groups, important physiological characteristics, challenges, and consequences are uniquely observed in athletes with a spinal cord injury (SCI) or cerebral palsy (CP). As a consequence, this chapter mainly focuses on SCI and CP, as these are the groups most affected by physiological differences when compared to able-bodied athletes.
**Physiological challenges and consequences for exercise performance**

**Heart rate and cardiac output**

The availability of oxygen in the mitochondria is crucial to obtain a continuous supply of energy in the form of ATP for muscular work. The volume of blood transported by the central circulation (cardiac output = stroke volume \times heart rate) and the consequent perfusion of the exercising muscle play an important role in this process. SCI leads to a pronounced reduction of cardiovascular, pulmonary, and metabolic ability. This is mainly caused by a reduced influence of the sympathetic nervous system, depending on the lesion level and status of the SCI as complete or incomplete. The SCI athlete with tetraplegia or high lesion level paraplegia above T6 shows a reduced maximal heart rate in comparison to able-bodied persons. Thus, as a resulting adaptation to cardiac work, cardiac dimensions are reduced in these athletes. Schmid and colleagues (1998) demonstrated that high-level trained basketball players reached lower values of cardiac dimensions in comparison to untrained able-bodied controls, but higher values than untrained SCI controls.

**Oxygen uptake**

Peak and maximal oxygen uptake are well established as excellent predictors of exercise capacity in Paralympic and Olympic athletes. Oxygen uptake and carbon dioxide production indirectly reflect the process of energy metabolism in the working muscle cell and can be measured using stationary or portable open-circuit spirometry systems (see Figure 3.1).

Aerobic training can massively increase maximal oxygen uptake and increase performance capacity in endurance-oriented competitive sports such as track and field, cycling, swimming, or Nordic skiing. As a consequence, in endurance-trained elite athletes, maximal oxygen uptakes that are more than 100% higher compared to values of untrained persons can be found (McArdle et al., 2015). The main trigger to increase oxygen uptake is the mitochondrial activity and therefore an increase in mitochondrial density, volume, and enzyme activity that is related to a high oxygen uptake.

**Coach’s Corner**

To increase aerobic fitness, athletes with high support needs (e.g., those with cerebral palsy) should progressively shift from short interval training to prolonged endurance training sessions.

Paralympic athletes reach values comparable to Olympic athletes in most of the groups already mentioned. A maximal oxygen uptake of more than 70 mL/kg/min in athletes with minimal disabilities has been measured (e.g., for cycling). Values correlate to training volume and intensity of

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**Figure 3.1** Stationary (left) and portable (right) open-circuit spirometric systems to determine oxygen uptake in Paralympic athletes.
the functional muscle mass. In Paralympic athletes with reduced functional muscle mass, peak performance is associated with reduced maximal values for oxygen uptake. Nevertheless, wheelchair athletes with no restriction in heart-rate response and oxygen uptake reach values of more than 50 mL/kg/min. Paralympic SCI athletes with reduced muscle mass and variations in the sympathetic/parasympathetic nervous system (e.g., tetraplegia and high paraplegia) and athletes with high support needs (e.g., those with cerebral palsy) perform their sport with oxygen uptake values clearly below this. In some cases such as wheelchair rugby players, values of even less than 20 mL/kg/min were found (see Table 3.1).

In general, children and adults with CP show reduced values of physical fitness in comparison to able-bodied persons. This seems mainly to be caused by a reduction in chronic physical activity. In CP athletes with high support needs, minimal effort often results in excessive metabolic responses, leading anaerobic resources to be used with limited influence on aerobic fitness.

In sports practice, oxygen uptake and carbon dioxide production can be used to quantify the energy expenditure at defined workloads (intensities). With respect to long-lasting training sessions and competitions, the quantification of energy consumption is of great importance for an adequate energy balance. In comparison with measured workloads, quantification of gross mechanical efficiency is possible (Abel et al., 2010) and helpful to control the effect of biomechanical changes in wheelchairs or cycles, or to control running economy.

Coach's Corner

Compression socks, adequate hydration, and abdominal binders can contribute to an increased cardiac output, which supports oxygen delivery to the working muscles in athletes with high SCI.

### Orthostatic and exercise hypotension

An impaired blood pressure control inducing low resting blood pressure and orthostatic hypotension due to the disruption of the sympathetic/parasympathetic nervous system is common in athletes with a lesion of the spinal cord above T6 (Ravensbergen et al., 2014). Symptoms such as light-headedness, nausea, or syncope can occur during a change of body position (e.g., fast movement from the supine to sitting position), but also during intense exercise. It is obvious that such symptoms can negatively influence quality of life, but also exercise performance as stroke volume is significantly reduced. This has some implications on cardiac output and thus oxygen delivery to the working muscles. Compression socks, adequate hydration, as well as abdominal binders can enhance venous return of the blood to the heart and thus increase stroke volume and cardiac output. In some cases sympathomimetic substances are also indicated to enhance blood pressure. However, these agents are on the prohibited list of the World Anti-Doping Agency (WADA).
and should be used by athletes only in case of an emergency.

**Autonomic dysreflexia and boosting**

Autonomic dysreflexia is an acute syndrome of excessive, uncontrolled sympathetic output caused by spinal reflex mechanisms. In general, individuals with SCI at or above the sixth thoracic neurological level are affected (Blackmer, 2003). Typical signs include high blood pressure, headache, flushing, sweating in the head and neck region, dilation of the pupil of the eye (mydriasis), and nasal congestion. Autonomic dysreflexia is caused by a noxious stimulus (e.g., full bladder or abdominal distension) below the lesion level, leading to a generalized sympathetic response and as a consequence to a vasoconstriction below the neurological lesion. The vasoconstriction is responsible for a rapid increase in blood pressure, which can go up to 300 mmHg for the systolic and 220 mmHg for the diastolic pressure (Karlsson, 1999), causing the symptoms mentioned.

**Coach’s Corner**

Coaches should be aware of the fact that boosting is forbidden and that they have an ethical responsibility to educate and sensitize athletes to guarantee fair competitions as well as to avoid positive doping controls.

Autonomic dysreflexia is a severe complication in individuals with a high spinal cord lesion and can lead to life-threatening situations. However, in elite wheelchair sports, athletes with a higher lesion above the sixth thoracic vertebra sometimes intentionally fill their bladder to induce autonomic dysreflexia in order to increase exercise performance (Burnham *et al.*, 1994) because of a higher sympathetic activation, leading to increases in blood pressure, stroke volume, peak heart rate, and peak oxygen consumption. Athletes and coaches have to be aware that this method, called “boosting,” is forbidden and strictly banned by the International Paralympic Committee (IPC). Thus, in some race categories blood pressure is measured before competitions. If the systolic blood pressure reaches a value of 180 mmHg or more, athletes are excluded from competition. From the 4,200 Paralympic athletes competing at the London Paralympic Games 2012, roughly 2% (approximately 100 athletes) fell into these categories where boosting might have induced an unfair performance-enhancing advantage.

**Aerobic and anaerobic exercise capacity**

Aerobic and anaerobic exercise capacity in wheelchair athletes is highly related to the level and completeness of the lesion and individual training status, as well as to the sports discipline. In general, higher peak heart rate and peak oxygen uptake responses can be expected with lower lesion levels. In endurance sports such as handcycling or wheelchair racing, world-class athletes with full arm and trunk function reach peak oxygen uptakes of more than 55 mL/kg/min at the end of an incremental exercise test, whereas these values in wheelchair rugby (a typical sports discipline for persons with tetraplegia) are sometimes below 20 mL/kg/min (see Table 3.1). These big differences represent the wide range of aerobic exercise capacities among athletes with an impairment. The same is true for anaerobic capacity, which is especially important for sprinters or in sports like wheelchair basketball or wheelchair tennis. Typically, sprinters reach higher peak power and peak lactate values compared to endurance athletes during a standardized anaerobic assessment. On the other hand, endurance-trained athletes tend to experience lower levels of fatigue.

**Coach’s Corner**

An ergonomic position and coordinated coupling of movement and respiration may help to optimize breathing performance.

**Respiratory function**

Based on a lesion-dependent loss of respiratory muscle innervation, respiratory muscle function is decreased in individuals with SCI (see Figure 3.2). Respiratory volumes and strength are dependent on lesion level and completeness, affecting
persons with a complete tetraplegia the most. As a consequence of this impairment, reduced respiratory muscle function and strength are found (Sipski and Richards, 2006), inducing for this population a typical rapid shallow breathing pattern. These conditions might contribute to a limitation in exercise performance. In some athletes, exercise performance may also be reduced due to severe spasticity, as this may limit physiologically correct respiratory maneuvers, leading to a reduction in oxygen uptake. Moreover, the forward crouching position in many wheelchair sports prevents efficient respiration and gas exchange in the lungs and additionally favors an inefficient rapid shallow breathing pattern. Moreover, during the propulsion of a wheelchair, some muscles of the upper body are concomitantly used for movement and breathing, a fact that possibly contributes to faster respiratory muscle fatigue during exercise and finally to reduced upper-body exercise performance. Taking all these circumstances into account, athletes with SCI will possibly benefit from well-directed respiratory muscle training interventions.

Muscle fiber distribution

Human muscles are divided into different types. The most accepted fiber typing separates type I and type II (type IIA and IIX) fibers. Type I fibers can be defined as slow oxidative fibers, type II as fast oxidative glycolytic (IIA) and fast glycolytic (IIX) fibers. The main differences occur in the dominant pathways of ATP synthesis, resistance to fatigue, and glycogen and myoglobin content, as well as twitch speed and force. Human muscles tend to be a mixture of these fiber types depending on the demands made of the specific muscle. In general, a distribution of 50% type I and 50% type II fibers was found in untrained able-bodied persons (McArdle et al., 2015).

Anaerobic training will increase the capacity of type IIX fibers, aerobic training the capacity of type I fibers. Different training modalities elicit different metabolic adaptations in muscles and selective hypertrophy of certain fiber types, but probably change the basic fiber type distribution only to some extent. In contrast, a long-standing SCI is
followed by a change in fiber type. Concerning paralyzed muscles, it was demonstrated that approximately 70 months post-injury the atrophied muscle (vastus medialis; femoral muscle) contained almost exclusively type II fibers (Burnham et al., 1997). Contrariwise on the upper extremity, Schantz et al. (1997) studied fiber typing in able-bodied persons and persons with SCI (paraplegia and tetraplegia), demonstrating an increase of type I fibers for the SCI population in comparison to the able-bodied controls (deltoid). The authors’ hypothesis was that different hormone levels or different types of muscular loads were relevant for these findings.

CP of the spastic type is associated with increased muscle tone. This could be described as the result of permanent high-intensity training and consequently as an influence of spasticity on muscle fiber type distribution. However, the international scientific literature shows inconsistent findings for fiber typing in athletes with CP. Pontén et al. (2005) analyzed eight persons with CP and included distribution of muscle fiber types, fiber sizes, and expression of developmental myosin, showing a significantly greater area of type II fibers in extensor muscles. In contrast, de Bruin and colleagues (2014) found no differences in fiber type distribution between persons with CP of the spastic type in comparison to able-bodied controls (flexor carpi ulnaris). Further systematic research is needed in this area to identify fiber type distributions as well as muscular adaptations to exercise in persons with CP.

### Coach’s Corner

The individual optimization of an athlete’s seating position supports postural control and maximizes upper extremity movement effectiveness and efficiency.

### Spasticity

Spasticity, a motor disorder of the central nervous system (CNS), results from damage to motor areas of the cerebrum (mainly in CP) or a dysfunction of the spinal cord (in SCI) and is characterized by a velocity-dependent increase in muscle tone, often with exaggerated tendon jerks (Winnick, 2011). In CP, spasticity primarily occurs in the flexors and internal rotators (upper extremity), with a great variety of forms, magnitude, and triggering factors. For athletes with CP or SCI, spasticity might lead to permanent contractures (Winnick, 2011), a rather painful and (concerning physical activities) restrictive situation. Spasticity has the potential to negatively influence quality of life (QoL) through restricting activities of daily living (ADL), causing fatigue and disturbing sleep (Adams and Hicks, 2005).

For the Paralympic athlete, spasticity in training situations and especially during competition is a challenging and often problematic situation. Management of spasticity following CP or SCI therefore is an important topic for athletes. Guidelines emphasize different pharmacological treatments, physical therapy, and (orthopedic) surgeries. Stretching exercise is a common treatment in the CP athlete. Surprisingly, however, there is inconclusive evidence of the effectiveness of stretching exercise for persons with CP (Barak et al., 2014).

On the other hand, symptoms of spasticity may increase stability in sitting and standing, facilitate the performance of some ADL and transfers, increase muscle bulk and strength of spastic muscles, and increase venous return. In some Paralympic competitions (e.g., throwing events), spasticity could positively influence performance.

### Body composition

Body composition is used to describe the percentages of fat, bone, water, and muscle in the human body. Only a small amount of scientific information on the body composition of the Paralympic athlete is available, and of course different sports require different body compositions. Nevertheless, in some sports a clearly reduced percentage of body fat in comparison to non-athletes is crucial for competition success. Therefore, the longitudinal control of body composition in elite Paralympic athletes is common. In long-lasting competitive sports like wheelchair racing over the marathon distance as well as cycling or swimming, with a main effect in aerobic capacity and a potential influence of body weight on performance, low body fat values are striven for to optimize performance.

The identification of different body compositions is possible by direct measurement (analysis of the
human cadaver) or by indirect estimations. In the area of elite sport, an indirect measurement of body composition is common and is mainly conducted via longitudinal control of energy balance as a basis for successful competition. Most of the Paralympic and Olympic athletes use skinfold measurement as well as bioelectrical impedance analysis (BIA) due to the potential costs and applicability of the measurements. For the Paralympic athlete (as well as for the Olympic athlete), it is impossible to define a perfect body composition. Different sports require different body compositions (e.g., running vs. power lifting). Weight and body composition changes are influenced by energy input and energy consumption. Energy input is influenced by food quality (carbohydrate, lipids, and proteins) and total volume (kcal/h). Energy consumption is influenced by resting metabolism, physical activity (including training and competition), and the thermic effect of food (McArdle et al., 2015). Especially in athletes with reduced muscle mass and a lower resting metabolism (e.g., SCI athletes with a tetraplegia), weight and body composition control is of great importance.

**Thermoregulation**

The impairment of the autonomic and somatic nervous system in subjects with SCI leads to a decreased thermoregulatory capacity compared to able-bodied individuals (Bhambhani, 2002). This means that skin blood flow and the ability to sweat below the lesion are disturbed, whereas individuals with higher lesion levels and a complete lesion are affected the most (Sawka et al., 1989). Compared to non-disabled athletes, sweat rates in athletes with paraplegia at the same relative upper body exercise intensity were reduced by 12–23% in cool and hot conditions (Price, 2006). The consequence of the lower heat tolerance of individuals with SCI is decreased exercise performance compared to able-bodied individuals, especially when exercising in hot environmental conditions (Bhambhani, 2002). In fact, body core temperatures of over 40 °C were found during handcycling competitions (Abel et al., 2006). Under these circumstances, cooling interventions and regular fluid replacement are recommended to avoid heat injury as well as to optimize exercise performance. However, it is often forgotten that disturbed thermoregulation can have some negative consequences in a cold environment as well. Wearing adequate warm clothes and shoes to prevent frostbite is mandatory for winter sports.

**Coach’s Corner**

The application of adequate cooling strategies (e.g., cooling vests) and fluid replacement help to avoid heat injury and enhance exercise performance in the heat.

Theoretically, athletes with CP might be exposed to a higher thermal stress during endurance exercise due to their diminished mechanical efficiency compared to able-bodied athletes. However, there are no representative data available to support this assumption scientifically. Although a study comparing thermal strain in children with CP with matched healthy controls found no differences between groups (Maltais et al., 2004), the content and design of the study are not representative for trained athletes with CP. Specific studies in elite sports are necessary before final conclusions can be drawn for athletes with CP.

It seems also worth mentioning that athletes with limb amputation can suffer from increased thermal stress (Ghoseiri and Safari, 2014). Over 50% of individuals with amputation were reported to experience heat or perspiration discomfort inside the socket of the prosthesis, leading to uncomfortable skin irritations. Scientists, manufacturers, and clinicians are challenged to find solutions to overcome this problem in the future.

**Gastrointestinal differences and nutrition**

When talking about general and sport nutritional aspects in athletes with a disability (mainly in wheelchair athletes with a SCI), several factors have to be taken into account and can differ from able-bodied athletes. During upper-body exercise, less muscle mass is active compared to whole-body or lower-body exercise in able-bodied individuals. Furthermore, there exist differences of muscle fiber type distribution, body composition, and energy expenditure during rest and exercise. In
general, resting energy expenditure depends on the completeness and level of the lesion, but is clearly below the value of an able-bodied person (Perret and Stoffel-Kurt, 2011). Although maximal energy expenditures of up to 700 kcal/h in handcyclists during intense endurance exercise were found (Abel et al., 2003), the involved muscle mass and energy expenditure during physical activity are much lower compared to able-bodied counterparts using their legs. In comparison to able-bodied individuals, the gastrointestinal transition times of persons with a SCI can be highly prolonged (Krogh et al., 2000). Therefore, it makes little sense to transfer nutritional recommendations from able-bodied athletes directly into wheelchair sports. Instead, specific studies (e.g., about supplement use) are necessary for this population of athletes.

At present, there exists only a limited amount of data in this area. One of these few studies (Perret et al., 2006) was not able to show an ergogenic effect of creatine monohydrate supplementation on 800-meter wheelchair racing performance when compared to a placebo. A recent study (Flueck et al., 2014) with elite wheelchair racing athletes found no significant ergogenic effect on 1,500-meter race performance after ingestion of either caffeine, sodium citrate, or the combination of these two supplements, but reported gastrointestinal side effects (mainly after the ingestion of sodium citrate) in five out of nine athletes. However, a closer look at individual responses seemed to show some ergogenic effects of caffeine supplementation at least in some athletes, a finding that was confirmed for sprint but not endurance performance in wheelchair rugby players (Graham-Paulson et al., 2015).

From a practical point of view, the following recommendations can be given when using potential ergogenic supplements in athletes with impairment. Individual testing of tolerance and side effects, a reduction of the supplement dosage compared to the recommendations for able-bodied individuals, or a dosage related to muscle mass and not to body mass seem to be mandatory. In order to avoid negative experiences during competition, it is highly recommended that substances be tested in advance during training sessions. Finally, antidoping regulations have to be kept in mind to avoid unnecessary positive doping results after supplement use. Thus, athletes have to be sensitized and educated in this respect, as many athletes seem not to be sufficiently informed of the current regulations or do not know where to find appropriate information (Graham et al., 2015). However, before any supplements are used, athletes should be aware of the fact that a balanced diet taking into account sport- and disability-specific needs plays the key role in achieving excellent exercise performance.

**Coach's Corner**

To optimize exercise performance multi-disciplinary guidance of the athlete is needed, which includes not only training and recovery strategies but also the concept of adequate nutrition and supplementation.

**Exercise testing and assessment methods**

Exercise testing on a regular basis is helpful to determine objectively the actual fitness level and to guide or optimize the training process of a Paralympic athlete. However, to generate adequate training recommendations, valid and reliable testing methods and assessment concepts are needed. Whenever possible, sport-specific testing methods have to be applied.

The special physiological characteristics of persons with a disability also have to be taken into account. For example, heart-rate regulation of an athlete with a motor and sensory complete tetraplegia is limited and it is not possible to steer the training process of such an athlete based on heart-rate recommendations. Thus, prescription of training intensities in this special group of athletes is often related to absolute speeds/workloads, lactate concentrations, or rating of perceived exertion (Goosey-Tolfrey, 2010).

There exists a variety of testing methods and concepts and each test reveals some advantages and disadvantages. Whereas laboratory-based tests allow exercise testing under standardized conditions, this can be difficult to guarantee during field testing. However, the advantages of the latter are the
real-life conditions simulating true competition. It is an illusion to believe in the ideal all-in-one test that fulfills all requirements at one time, as such a test simply does not exist. Thus, before an exercise test is performed, coaches and athletes should clearly define the outcome parameters needed as well as the optimal time point of testing (e.g., off season, pre-competition). Based on this information, the best testing and assessment concepts can be defined.

However, whatever testing concept is used, it is important to note that for the longitudinal comparison of test results, the same test protocol ideally performed under standardized conditions always has to be used. Finally, before testing starts it is useful to fill in a standardized questionnaire concerning important factors such as training, sleep, nutrition, and medication, which might have some impact on test results. Ideally, an athlete prepares for a test in a similar way for a competition.

**Anaerobic exercise testing**

To determine anaerobic power and capacity, the Wingate test is a reliable and commonly used option (Jacobs et al., 2003, 2005). Depending on the disability (e.g., SCI, amputation), this 30-second all-out test can be performed on a cycle ergometer, an arm-crank ergometer, or a special wheelchair ergometer. The chosen ergometer resistance is proportional to the athlete’s body weight and the aim is to perform as many revolutions as possible during 30 seconds. Peak power (P5max), average power (P30), time to peak, time to peak power, and the fatigue index (FI) can be measured. These values provide information on an athlete’s anaerobic power (P5max), the individual potential for acceleration during an initial phase (time to peak), the anaerobic capacity (P30), and fatigue (FI).

At present there exist no standardized recommendations for how the appropriate resistance for the test is determined. However, it seems obvious that the resistance for upper-body exercise is clearly lower (about half or less) compared to leg exercise because of the differing size of the muscle mass. Furthermore, the resistance also depends on the functional ability, muscle mass, lesion level, and gender of the athlete being tested. In some laboratories, the resistance is defined based on the personal daily experiences of the athlete after several years of testing. However, what is most important is always to choose the same resistance for the same athlete to warrant reliable comparison of test results. As athletes usually perform the second test on a higher level than the first, a familiarization trial is recommended, although there seems to be a high test–retest reliability of the 30-second Wingate test in persons with a para- or tetraplegia (Jacobs et al., 2003, 2005). Wingate testing is recommended for sports disciplines that deal with high anaerobic demands during competitions. This includes sprinters, but also sports such as wheelchair basketball, rugby, or tennis.

**Aerobic exercise testing**

A number of aerobic exercise testing concepts also exist. Key parameters in aerobic exercise testing are the maximal oxygen uptake and the so-called maximal lactate steady state (based on threshold concepts also termed anaerobic or lactate threshold), which serves as the gold standard for the prescription of training intensity zones for coaches and scientists. The maximal lactate steady state (MLSS) is defined as the highest sustainable workload over time without continuous blood lactate accumulation (Beneke, 1995) during the last 20 minutes of a 30-minute constant-load endurance test. In general, to determine MLSS accurately several exercise tests on different days are needed. However, as this seems not to be feasible for daily practice, several testing concepts for an indirect determination based on one single test were developed. These concepts refer to heart rate (Conconi et al., 1982), ventilatory parameters (Wassermann et al., 1973), and lactate (Svedahl and MacIntosh, 2003). Three of the most common methods used are presented here.

**Ramp test**

The ramp test typically serves to determine maximal oxygen uptake, defined as the maximum amount of oxygen that can be used per unit time. This parameter is the most important measure of cardiorespiratory fitness, but needs the availability of expensive equipment and a sport-specific
ergometer such as an arm crank ergometer, treadmill, wheelchair, or double poling ergometer (see Figure 3.3). For the determination of maximal oxygen uptake, a ramp test (incremental exercise testing) is the method of choice. Ideally, the increment is chosen so that maximal oxygen uptake is reached within 8–12 minutes. For example, such a protocol performed on an arm crank ergometer in athletes with a tetraplegia could start at 0 Watts with an increment of 10 Watts/minute (or 1 Watt per 6 seconds), whereas the increment is 20 Watts per minute (1 Watt per 3 seconds) in trained athletes with a low-level paraplegia.

Based on respiratory gas exchange parameters such as the ventilatory equivalent for oxygen measured during the ramp test (sometimes this method is also applied in combination with step tests), the determination of the so-called ventilatory threshold (sometimes also termed lactate threshold) is non-invasively possible as well, which gives a good estimate of submaximal aerobic fitness. The principal idea behind this analysis is that once lactate starts to accumulate, the release of carbon dioxide becomes overproportional due to increased blood bicarbonate buffering. The relation of oxygen uptake and carbon dioxide release as well as changes in ventilatory volumes can easily be detected and analyzed by a metabolic cart, and gives some indication of an athlete’s actual aerobic performance level.

**Lactate step test**

In general, lactate step tests are based on the principle of incremental exercise testing. Starting with a fixed workload, resistance is systematically stepwise increased after a predetermined time interval. Time intervals and increments typically range between 3 and 6 minutes and 10 to 30 Watts depending on sports discipline, disability, and individual fitness level. The tests are performed to the athlete’s exhaustion and a capillary blood lactate sample is taken at the end of each stage. For the analysis, a lactate-performance curve is used to detect the so-called lactate threshold (sometimes also based on ventilatory parameters), which marks the exercise intensity where the highest amount of energy can be derived aerobically without the accumulation of lactic acid in the blood. However, one has to be aware of the fact that the detection of an individual lactate threshold depends greatly on the test protocol (step duration and increment) and the analysis method applied. For long-term comparison, it seems therefore crucial always to apply identical test protocols and methods of analysis.

**Coach’s Corner**

Standardized laboratory exercise testing on a regular basis is helpful to optimize the monitoring and development of an athlete’s training program.
Lactate minimum test

The lactate minimum test seems to be a promising method to determine MLSS (an important parameter for predicting endurance performance and designing training programs) by means of one single test. In general, the lactate minimum test consists of two parts: the first serves to induce severe blood lactate accumulation, whereas the second is an incremental exercise test starting at a moderate intensity. During the early phase of the second test, lactate is metabolized until the so-called lactate minimum is reached, before the lactate concentration starts to rise again (see Figure 3.4).

A close relationship was found between the lactate minimum and MLSS in elite wheelchair racing athletes (Perret et al., 2012). Besides the fact that it seems to be possible to determine MLSS by means of one single test, this testing concept appears to offer some further advantages. In combination with an automated metabolic measurement system, it is possible concomitantly (i.e., at the same time) to determine maximal oxygen uptake during the first test part (Dantas de Luca et al., 2003), and test results seem to be independent of the previous nutritional status (Tegtbur et al., 1993) or of the investigator’s experience (Knoepfli-Lenzin & Boutellier, 2011). However, compared to the ramp and lactate step tests, the lactate minimum test is rather time consuming, and for feasible test results it is important that athletes perform to exhaustion during the first part (Labruyère and Perret, 2012).

Field testing

The Paralympic athlete’s performance capacity has increased enormously during the last few years and has clearly reached new levels, resulting in numerous world records. The main reasons for this impressive development in most forms of sport are athletes’ optimized training activities and an increased training quality developed between athlete, coach, and sport scientist. Field-based tests are commonly used in different Paralympic sports like swimming, track and field, cycling, and wheelchair sports, as well as for winter sports. Although field-based tests cannot offer the quality of tests performed in laboratory settings, they are easy to run, inexpensive (or free), practical, and can be performed more frequently (Goosey-Tolfrey and Leicht, 2013).

The purpose of a field-based test mainly is twofold: to evaluate the actual performance capacity under sport-specific conditions and to establish or control accurate training intensities. In some scientific studies quality criteria for field tests can be verified. Vanlandewijck et al. (1999) demonstrated a high correlation (r = 0.93) between a wheelchair basketball sprint test and the well-established laboratory Wingate anaerobic test. An overview of
different field tests for wheelchair athletes is given by Goosey-Tolfrey and Leicht (2013).

**Strength assessments**

The main reasons for performing strength tests are to evaluate initial levels and then to assess changes. Static and dynamic tests of Olympic athletes are typically conducted with dynamometers, load cells, and tensiometers, or more elaborate isokinetic and motor-driven testing devices. These methods are equally used to test the Paralympic athlete, focused on the individual abilities to use sport-specific muscles. For strength assessments in wheelchair athletes, special wheelchair ergometers can be used.

**Body composition assessment**

A large variety of laboratory and field-based tests to estimate body composition have been established for elite athletes. They differ mainly with regard to costs and applicability. For routine testing of Paralympic athletes, measuring body composition is commonly done by means of skinfold or bioelectrical impedance analysis (BIA), as they are relatively low priced and easy to conduct. Nevertheless, the reliability and validity of these measurements for athletes with impairment are partly questioned in scientific discussions (Cirnigliaro et al., 2013). Other methods are generally more often applied in clinical studies, but are being used with more regularity in the exercise physiology laboratory.

**Dual-energy X-ray absorptiometry (DXA)**

DXA scans (see Figure 3.5) were primarily developed to evaluate bone mineral density. DXA reliably and accurately quantifies fat and non-bone regional lean body mass, including the mineral content of the body’s deeper bone structures. The bone mineral content of the lower extremities is crucial in SCI athletes and optimizing lean body mass is one goal to enhancing performance. Two distinct low-energy X-ray beams with short exposure, low radiation dosage, and different energy levels are aimed at the athlete’s bones and soft tissue. Areas to a depth of approximately 30 cm penetrate the athlete’s body. Soft tissue absorption can be subtracted out (McArdle et al., 2015). The radiation received by the athlete during the scan is quite low and comparable to a long-distance flight.

![Figure 3.5 DXA scan to determine body composition in a person with a SCI. Reproduced with permission of Swiss Paraplegic Centre, Department of Radiology.](image-url)
DXA shows strong relationships to other clinical measurements and a high association with hydrostatic weighing (McArdle et al., 2015). Due to the availability of centers able to perform a DXA, as well as the costs of the method, it has been typically reserved for clinical studies. Nevertheless, DXA can be described as the gold standard for the assessment of body composition. In addition to DXA, computed tomography (CT) and magnetic resonance imaging (MRI), which is also known as magnetic resonance tomography (MRT), are other possible imaging methods to estimate body composition.

**Hydrostatic weighing**

Hydrostatic weighing, also referred to as underwater weighing, hydrostatic body composition analysis, or hydrodensitometry, is a technique for measuring the mass per unit volume of a person’s body. The procedure is based on Archimedes’ principle, using the following three measurable values: the weight of the body outside the water, the weight of the completely immersed body, and the density of the water. Hydrostatic weighing (underwater) is conducted in a pool or a tank, with the athlete seated with the head above water. After a forced maximal exhalation, the head is slowly lowered under water and the breath is held for some defined time. The procedure is repeated 8–12 times to obtain a dependable underwater weight score. Body volume calculation requires subtracting the buoyant effect of the residual lung volume measured immediately before, during, and following the underwater weighing. By using prediction equations, body composition can be calculated from body density.

Although hydrostatic weighing is a so-called gold standard to determine body composition in able-bodied persons, it is almost never used in Paralympic sport due to the effort and disturbance of the athlete, as well as a lack of specific equations that are crucial for valid results (Heyward, 1996).

**Body volume measurements**

A relatively new procedure to measure body composition is the Bodpod system, a tool to identify body fat by measuring body volume and body mass in a small chamber (dual-chamber fiberglass shell). Measurements are based on similar principles to those applied for underwater weighing. Body volume is identified by measuring the initial volume of the empty chamber and then the volume with the person inside. Body mass is determined on an electronic scale inside the chamber. The subject is sitting in the chamber wearing a tight-fitting swimsuit to ensure reliable and accurate measurement. Body volume represents the initial volume minus the reduced chamber volume. Body density is computed as body mass divided by body volume including a correction. Body density is converted to percentage body fat using the Siri equation (McArdle et al., 2015).

Comparisons of the Bodpod system to other measurements methods, including DXA and hydrostatic weighing in able-bodied persons, showed differences large enough not to be interchangeable (Mahon et al., 2007). The measurement reduces the effort and disturbance for the Paralympic athlete in comparison to hydrostatic weighing. Nevertheless, equations for the Paralympic athlete are missing and should be evaluated in future research.

**Skinfold measurements**

Skinfold thickness is a simple means of estimating body composition, which is widely used in elite sport as well as in scientific studies. Measuring skinfold thickness requires firmly grabbing a fold of skin and subcutaneous fat with the thumb and forefingers, pulling it away and from the underlying muscle tissue following the natural contour of the skin of the skinfold (see Figure 3.6). The skinfold thickness is measured in millimeters by means of a caliper for the distance between two points.

**Coach’s Corner**

Skinfold measurements and bioelectrical impedance analysis (BIA) are simple and cheap methods for the longitudinal monitoring of an athlete’s body composition.

Taking into account 3–12 different specific skinfolds, there are different ways to use the information. Mostly the skinfold scores are combined to indicate relative and absolute fatness by using
different equations. Skinfold measurement is especially useful to monitor changes in percentage body fat after an intervention (training, diet). There has been a proliferation of equations for the estimation of body composition from skinfolds, yet the existing published equations are associated with large random errors or significant systematic errors (McArdle et al., 2015). The measurement is dependent on the investigator's experience and on the different equations.

With regard to the use of skinfold measurement to estimate body composition for Paralympic athletes, there is still need for representative studies in order to gather more information and to adjust the formulas to the specific characteristics of the Paralympic athlete. At present, skinfolds might best be regarded as indices (rather than measures) of body fatness in individuals or as a means of estimating the body fatness of groups. Nevertheless, individual changes can be monitored reliably. In addition, skinfolds can be measured and reported as raw data to profile the skinfolds and their potential changes due to training or diet over time.

**Bioelectrical impedance analysis (BIA)**

Body impedance analysis is based on the principle that due to the greater electrolyte content, a small alternating current flowing between two electrodes passes with different speeds through different hydrated fat-free body tissues and extracellular water compared to fat or bone tissues. Therefore, in fat-free components a lower electrical resistance is present. Body water therefore plays an important role in BIA. The analysis can be conducted with the athlete lying on a flat non-conducting surface with attached electrodes (e.g., hand and foot). The impedance to the flow between the source and the detector electrodes is determined (see Figure 3.7). The impedance value as well as body mass, stature, gender, and age are used to compute percentage body fat from the Siri equation or other density-converting equations (McArdle et al., 2015).

The reliability of BIA mainly depends on the additional input of data. It represents a non-invasive, safe, relatively easy, and generally reliable method to measure body water. The technique strongly requires that measurements are conducted under standardized conditions, including electrode placements, body position, hydration status, skin temperature, and previous food and beverage intake. If these conditions are strictly controlled, BIA is a reliable method to measure body composition in Paralympic athletes. Although there are some studies of BIA and persons with SCI or CP (Oeffinger et al., 2014), there is a lack of
information concerning special equations for athletes with special requirements.

**Training recommendations**

**Endurance training**

Optimal performance in Paralympic sports is the result of optimal preparation, among other factors. One of the key determinants in the preparation of an athlete is training. An optimal training program is the key to success in Paralympic sports and nowadays requires an individualized sport- and task-specific approach. Knowledge about the basic physiological exercise principles to determine accurately the different training zones for each athlete allows for the development of a well-balanced training program. The minimal intensity threshold is the exercise level that is minimally required to achieve a training effect, and typically refers to an exercise intensity level eliciting 50% of the peak oxygen uptake (Garber et al., 2011). In elite able-bodied cyclists, this corresponds to 60% of the heart rate reserve (HRR; maximal heart rate – resting heart rate). For the Paralympic athlete without any disturbance of cardiac function, this seems to be comparable.

At lower exercise intensities, muscles obtain a vast amount of their energy supply from fat metabolism. This system can provide energy for longer periods, but has limited power. At moderate exercise intensities, fat oxidation has reached its maximal rate of energy production. Above this intensity, the extra energy is supplied by the oxidation of carbohydrates and fat oxidation is strikingly reduced. However, the carbohydrate reserve in a human body is limited, therefore restricting the duration of exercise at these intensities. This intensity mainly determines the performance level in endurance sports.

As already mentioned, MLSS refers to the highest exercise level without the accumulation of lactic acid. Above this exercise intensity, lactate production in the muscles exceeds lactate elimination and the blood lactate concentration gradually increases. This point is critical, as exercise intensities below this level can be sustained for longer periods without the onset of muscle fatigue, whereas higher exercise intensities rely on an increasing anaerobic energy supply, which is generated in the absence of
oxygen, leading to an extra accumulation of lactate that causes muscle fatigue. Based on the MLSS (or anaerobic threshold), a number of training zones are commonly used to describe different training intensities, as follows.

**Recovery training zone**

The purpose of training in this zone is to recover from heavy training or competition loads. The intensity in this zone is lower than the minimal intensity threshold, with a very low heart rate and short training duration. Training in this zone stimulates recovery, but has no direct training effect.

**Extensive endurance training zone**

Exercise in this zone serves as a basis for each training schedule, and stimulates fat metabolism. Extensive endurance training allows the energy supply from mainly fat oxidation to be maintained at higher exercise intensities during training and competition. Extensive endurance training therefore prepares athletes for more intensive training efforts, and is very suitable in long-term endurance sports. The intensity during this type of training is rather moderate; however, the duration is long (longer than competition duration).

**Intensive endurance training zone**

During intensive endurance training, the energy supply is mainly generated through the oxidation of carbohydrates. The lactate concentration in the muscles is higher, but the balance between production and elimination remains stable. Since fair amounts of carbohydrates are oxidized during this type of training, the training duration is limited. The intensity during this type of training is high, however.

**Extensive interval training zone**

The intensity for this type of training is close to the MLSS. Exercises in this zone can be sustained for 30–60 minutes. The aerobic energy supply (fat and carbohydrate metabolism) reaches the maximal intensity that allows a balance between lactate production and elimination. Extensive interval training should be conducted in the immediate build-up to competition. As the impact of training sessions in this zone is high, this training mode should not be part of the training schedule too often. However, this differs from athlete to athlete and thus individual training adaptations are strongly recommended.

**Intensive interval training zone**

This represents the anaerobic training zone. The purpose of anaerobic training is to increase an athlete’s tolerance to lactate accumulation. This high-intensity interval training (HIIT) is a very strenuous type of training, as intensity is nearly maximal and requires a large degree of recovery. Variation of intervals (e.g., lengthening or reducing the high-intensity blocks and the recovery blocks) is possible and crucial for training success.

**Strength training**

As already mentioned, the increasing performance capacity of the Paralympic athlete is the result of an optimal training strategy, among other factors. Improvements in total strength are generated with sport-specific training such as in swimming and cycling (Fulton et al., 2010), as well as with non-sport-specific weight training (Dingley et al., 2015). Non-sport-specific weight training for the Paralympic athlete is often similar to that for the Olympic athlete, with the additional need for barrier-free access to rooms and weight-training equipment (see Figure 3.8). At times, additional assistive personnel are required for the training session.

Strength training, as non-specific training, commonly uses the technique of progressively increasing the force output of the muscle through incremental weight increases, and employs a variety of exercises and types of equipment to target specific muscle groups. A common training strategy is to set the volume and frequency the same each week (e.g., training 2–3 times per week, with 2–3 sets of 8–12 repetitions each workout), and steadily increase the intensity (weight) on a weekly basis. However, to maximize progress to specific goals, individual...
programs may require different interventions, such as pyramid sets (weight-training sets in which the progression is from lighter weights with a greater number of repetitions in the first set to heavier weights with fewer repetitions in subsequent sets), or decreasing the weight and increasing volume or frequency. If a strength-training intervention aims to increase maximal force with only small changes in muscle mass (e.g., for the high jump), the training strategy is oriented to high intensities (e.g., one set of 1–5 repetitions at 80–100% of the one-repetition maximum).

Coach’s Corner

Core stability training builds the basis for more force generation in most sport disciplines and is highly recommended for all Paralympic athletes, whereas wheelchair users can train under non-trunk-supported conditions outside of the wheelchair.

Although strength training is one of the key determinants in the preparation of the Paralympic athlete, it is important to stress that overload and potential injuries (e.g., of the shoulder) are not only problematic in optimal preparation for competitions, but are crucial for all activities of daily life. Therefore, careful planning and handling of strength training in Paralympic sport are mandatory.

Respiratory muscle training

In general, there are two types of respiratory muscle training methods: respiratory endurance training by means of isocapnic hyperpnea, and respiratory strength training based on resistive loaded breathing. In able-bodied athletes both methods showed positive effects on exercise performance (Illi et al., 2012). However, to date studies that include Paralympic athletes are scarce. Nevertheless, athletes with a limited respiratory muscle function such as persons with SCI might possibly benefit from a well-directed respiratory muscle training program.

Isocapnic hyperpnoea training

After a six-week period of isocapnic hyperpnoea training, a significant increase in respiratory muscle endurance and an improvement in 10-kilometer race time in wheelchair racing athletes were found (Mueller et al., 2008). The isocapnic hyperpnoea training consisted of five 30-minute sessions per week. Typically, an isocapnic hyperpnoea training program starts at an intensity corresponding...
to about 60% of maximal voluntary ventilation and a breathing frequency of about 30 breaths per minute. During the course of the training period, respiratory frequency is gradually increased in order to maximally challenge the respiratory system.

A further study (Perret and Mueller, 2007) investigated whether respiratory muscles have the potential to accelerate blood lactate elimination after exhaustive upper-body exercise. It was suggested that the advantages of such an intervention would support a quicker recovery during competitions and allow a faster refilling of arm muscle glycogen stores, as these muscles were no longer used for active recovery. However, results showed no differences in lactate metabolism after exhaustive arm exercise comparing isocapnic hyperpnoea, passive recovery, or active recovery by means of arm cranking at a low intensity. Thus, isocapnic hyperpnoea training cannot yet be recommended as a method to enhance the recovery process after exhaustive arm exercise.

**Coach’s Corner**

Strapping and abdominal binders have the potential to support breathing, venous return, and core stability. However, at the same time mobility and range of action can be significantly reduced, which makes a well-estimated individual adaptation of such interventions necessary to avoid a negative impact on performance.

**Practical aspects**

The respiratory training studies in Paralympic athletes already mentioned clearly underline the fact that results from studies in able-bodied persons cannot be directly transferred to athletes with SCI. Thus, respiratory training programs have to be individually tailored to the special needs of the Paralympic athlete population. As pre-fatigued respiratory muscles are known to limit subsequent exercise performance (Mador and Acevedo, 1991), it is important to stop a respiratory training program early enough before important competitions. Ideally, respiratory muscle training is coordinated with the daily physical training process and performed in a position similar to that normally taken during a competition. Finally, there is some evidence that abdominal binders can support respiratory function and performance, as recently shown in wheelchair rugby players (West et al., 2014).

**Performance under extreme conditions**

Extreme conditions such as heat, humidity, and altitude or air pollution may put additional stress on Paralympic athletes and affect their exercise performance. However, if a closer look is taken at the venues of Paralympic Games (e.g., Salt Lake City 2002, Beijing 2008, or Rio 2016), it can be seen that athletes are regularly faced and challenged with extreme environmental conditions during the...
course of their personal preparation for competi-
tions.

Heat and humidity
It is a matter of common knowledge that heat
and humidity have a negative impact on exercise
performance. This effect might be even more pro-
nounced in athletes with SCI due to their already
decreased thermoregulatory capacity (Bhambhani,
2002). There are options that can efficiently help to
optimize exercise performance and to prevent heat
injury in Paralympic athletes. The most important
action seems to be a sufficient acclimatization time
of about 10 days. At competition or training days in
the heat (see Figure 3.9), passive precooling inter-
ventions by means of cooling vests, ice baths, or
water immersion–based hand cooling (Griggs et al.,
2015) were used and have been proven to be ben-
eficial in reducing core body temperature, which
minimizes heat stress and thus improves exercise

Figure 3.9 Specific wheelchair training under hot and
humid conditions in a climate chamber while testing a
cooling vest.

performance in the heat. In team sports such as
wheelchair basketball or wheelchair rugby, water
sprays are commonly used to make athletes more
comfortable. However, at present there seems to be
no scientific evidence of this having a significant
impact on thermoregulation (Pritchett et al., 2010).
Further, athletes should wear adequate clothing,
drink sufficiently to warrant a well-hydrated state,
adapt the warm-up strategy to avoid unnecessary
overheating before a competition, and try to stay in
the shade as much as possible. However, whatever
strategies are applied for a competition, practicing
them in advance during training sessions is highly
recommended.

Altitude
Compared to sea level, oxygen partial pressure
decreases with increasing altitude, which neg-
atively affects endurance exercise performance.
Acute exposure to altitude causes a decrease in max-
imal oxygen uptake, blood oxygen saturation, and
blood buffer (bicarbonate) capacity, as well as an
increase in minute ventilation. These effects are at
least partially reversed after chronic exposure to
altitude. Thus, if competitions take place at alti-
tude, an acclimatization period of about one week
prior to the competition is recommended. Further,
there exist different concepts of altitude training
schedules and models sometimes referred to as “live
high – train high,” “live high – train low,” or
“live low – train high.” These different concepts
cause different physiological adaptations and thus
the choice of a certain concept depends on the
defined aims of the training program. From the
able-bodied literature there seems to be some evi-
dence that well-directed altitude training programs
(Fudge et al., 2012) may enhance sea-level perfor-
ance as well as performance at altitude. However,
the question of whether these findings are also true
for Paralympic athletes with, for example, SCI has
not yet been answered due to a lack of available data
in the peer-reviewed literature.

Pollution
In the past decade, the Paralympic Games were
held in some of the most air-polluted megacities
in the world (Zhang et al., 2007). Based on this fact, many experts warned of decreased athletic performance and serious health problems related to air pollution. Health problems mainly concern the cardiovascular system and the respiratory tract and include difficulties in breathing, respiratory discomfort, airway irritation, or asthma-like symptoms, which lead to severe decreases in athletic performance (Lippi et al., 2008). The pollutants that seem to cause the greatest problems are nitrogen dioxide (NO$_2$), ozone (O$_3$), carbon monoxide (CO), and sulfur dioxide (SO$_2$). From a practical point of view, it is recommended to avoid polluted city areas as much as possible for outdoor training sessions. Further, training should be held in the early hours of the day, as during this time the lowest concentrations of pollutants are expected.

### Coach’s Corner

The burden of pollution to an athlete is termed the effective dose (ED) and is the product of the pollutant concentration × minute ventilation × exposure time. Coaches should consider this rule and if possible avoid training in a polluted environment. If this is not possible, wearing face masks, nasal lavage, and – if indicated – the use of asthma medications can help to reduce health problems.

### Conclusion

In general there are few fundamental differences concerning the physiology of Paralympic and Olympic athletes. However, especially in athletes with CP or SCI, some special physiological characteristics, challenges, and consequences can be observed. A higher lesion level SCI leads to a reduced or absent influence of the sympathetic nervous system and affects the regulation of heart rate, stroke volume, cardiac output, and blood pressure. Further, compared to able-bodied athletes, differences in muscle fiber distribution, body composition, resting energy expenditure, respiratory function, or thermoregulation can be found. All these factors may reduce exercise performance to some extent. This negative impact on performance might be even more pronounced under extreme environmental conditions such as heat, humidity, altitude, or air pollution. However, assessment methods to determine physical performance (e.g., aerobic and anaerobic performance tests, strength tests) or body composition are often similar to the methods used in able-bodied athletes and can help to objectively support and guide the training process of a Paralympic athlete as well. In order to generate adequate training recommendations, valid and reliable testing and assessment methods are needed. Whenever possible, specific testing and training interventions tailored to the special physiological needs of an athlete with impairment should be applied. Examples of such specific interventions include the application of cooling methods (e.g., cooling vests), respiratory muscle training, or nutritional interventions (e.g., caffeine supplementation).

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Chapter 4
Paralympic sports medicine

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Introduction

Due to the growing international profile of the Paralympic Movement, competitive sport opportunities for athletes with impairment, from grassroots to elite, continue to expand rapidly. At the same time, the field of Paralympic sports medicine has emerged as an exciting and innovative area of both medicine and science. Optimizing athlete health and safety is important for both enhancing sports performance and preventing injury. Additionally, for athletes with impairment, sport participation may offer an innovative tool for rehabilitation, building mobility, strength, and fitness while also promoting social integration and positive peer mentoring. For this reason, there is an increased realization that engaging with Paralympic athletes offers the chance for healthcare professionals to work at the exciting intersection of rehabilitation with sports and exercise medicine.

The use of sport as a tool for public health promotion also deserves special mention. According to the World Health Organization’s 2011 World Report on Disability, individuals with impairment make up at least 15% of the global population, yet remain an often segregated and underserved minority group (World Health Organization, 2011). Numerous health disparities that plague the general population, such as obesity and cardiovascular disease, disproportionately affect individuals with impairment. In addition to offering opportunities to elite athletes, Paralympic sport has the opportunity to promote healthy, active lifestyles and decrease the prevalence of chronic, non-communicable disease within the global population of people with disabilities (see Figure 4.1).

When outlining sports medicine considerations for athletes with impairment, it is important to note that the majority of the health and medical needs of Paralympic athletes are identical to the needs of athletes without impairment. For this reason, team physicians, athletics trainers, and allied health professionals should feel comfortable working with this population. For those considerations that are unique and require special attention, further information will be provided here.

Injury and illness epidemiology

The physical, psychological, and social benefits of participating in sports and recreational activities have been well described in individuals with impairment. These benefits have been shown
to translate to improvements in self-perceived quality of life, reduced risk of secondary illness, and decreased utilization of hospital resources. It is generally accepted that participation in competitive sport should improve health, rather than subjecting an athlete to an increased risk of injury and illness. Although important for all athletes, this concept requires additional emphasis within Paralympic sport. For example, athletes with spinal cord injuries who use wheelchairs for everyday locomotion as well as for sport (as in wheelchair basketball or rugby) may develop overuse injuries of the shoulders, leading to early degeneration of the joint and ultimately the need for shoulder replacement at a fairly young age. Undergoing this type of procedure would have a significant impact on the athlete’s everyday mobility and quality of life. Therefore, the longitudinal study of both injury and illness epidemiology in Paralympic sport is important, as findings may assist in the formulation of prevention strategies.

A model for the systematic development of sports injury-prevention strategies has been developed and is used by the International Paralympic Committee (IPC) Medical Committee. This begins with quantifying the problem in terms of incidence and severity, then establishing the etiology and mechanisms of injury, followed by the development and implementation of injury-prevention strategies that can be assessed for effectiveness. When considering Paralympic sport, it is clear that the understanding of illness and injury is still in the early stages of this model.

The history of injury and illness surveillance in Paralympic sport

In comparison to research on able-bodied athlete populations, there are relatively few epidemiological studies monitoring injury and illness in Paralympic athletes. Therefore, a detailed understanding of illness and injury patterns in this complex population remains an ongoing focus of sports medicine research.

Although studies with a focus on sports injuries in Paralympic athletes began to appear in the medical literature several decades ago, these were predominantly limited to reports on individual athletes, single-coded events (focusing on just one specific disability or sport), or single-country teams.

Coach’s Corner

Paralympic athletes may experience increased functional difficulties due to sports-related injuries. For example, a shoulder injury in a wheelchair basketball player may have an impact on sport performance, but also wheelchair use or transfers in day-to-day life.
As a major step forward, Ferrara et al. (2000) reported prospectively on the proportion of injuries and illnesses sustained in US para-athletes over the timeframe 1990–96. Attempts to address injury epidemiology began in earnest in 2002 with the creation of a larger, prospective study of athletes participating in the Paralympic Winter Games. However, this remained limited by a lack of consensus regarding the definition of reportable injury, unconfirmed medical diagnoses, lack of exposure data, and a small sample size. Additionally, the incidence of illness during a major multi-coded Paralympic competition had never been evaluated.

In an attempt to address the historical limitations of earlier studies, an advanced online injury and illness surveillance system was implemented for the London 2012 Paralympic Summer Games. This required the development of a novel web-based surveillance tool for use by team medical staff. The setting of the London 2012 Paralympic Games, with wi-fi accessibility throughout the village and at all venues, allowed for easier collection of more detailed injury and illness data. This system also included features to enhance compliance by team medical staff and facilitate the collection of exposure data, in turn allowing for more accurate calculation of the incidence rates of illness and injury. The use of this novel system, together with the existing local organizing committee medical record-keeping platform, enabled the largest, most comprehensive study to date for the evaluation of injury and illness in Paralympic athletes. A total of 49,910 athlete days were recorded, with 10,695 athlete days monitored in the pre-competition period and 39,215 athlete days monitored during the competition period. This system was also successfully implemented during the Sochi 2014 Paralympic Winter Games.

**What is considered an injury or illness?**

In epidemiological studies, it is important to explain exactly what is meant by the terms “injury” and “illness.” For the purposes of the Paralympic Injury and Illness Surveillance Study, an injury or illness episode was defined as any encounter of an athlete receiving medical attention, regardless of whether this resulted in absence from competition or training.

An injury was defined as any newly acquired injury as well as exacerbations of pre-existing injury occurring during training or competition, either during the Games or immediately before. Injuries were classified as acute traumatic, acute-on-chronic, or chronic (overuse). It was also noted whether the injury resulted in “time loss” from training or competition, defined as more than one day of absence. Time-loss injuries were considered more severe. An acute traumatic injury was defined as an injury that was caused by an acute precipitating event. An acute-on-chronic injury was defined as an acute injury in an athlete with prior symptoms of a chronic injury in the same anatomical area. A chronic (overuse) injury was defined as an injury that developed over days, weeks, or months and was not associated with an acute precipitating event. A medical illness was defined as any newly acquired illness as well as exacerbations of pre-existing illness that occurred during training or competition, either during the Games or immediately before.

**Paralympic Injury and Illness Surveillance Study: Summer sports**

The overall injury rate in the London 2012 Paralympic Games study was 12.7 injuries/1,000 athlete days. The overall incidence proportion (percentage of athletes with an injury) was 15.1 (Willick et al., 2013). Team medical staff may find these data helpful when planning medical support for teams attending multi-coded events. Rates of injury vary greatly between sports.

**Injury rates by sport**

Injury rates in the different summer Paralympic sports are shown in Figure 4.2. The five sports

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**Coach’s Corner**

- **Acute traumatic injury**: Any injury caused by a precipitating traumatic event.
- **Acute-on-chronic injury**: An acute injury in an athlete with prior symptoms of a chronic injury in the same anatomical area.
- **Chronic (overuse) injury**: An injury that developed over days, weeks, or months and was not associated with an acute precipitating event.
with the highest injury rates are football 5-a-side, powerlifting, goalball, wheelchair fencing, and wheelchair rugby. The five sports with the lowest injury rates are shooting, rowing, sailing, road cycling, and boccia. These data are helpful to team medical staff to help estimate the number of injuries for which they should be prepared. Perhaps more importantly, they allow for determination of which sports need to be assessed in greater detail to determine risk factors for injury.

**Anatomical regions most affected by injury**

Injury rates per anatomical region are shown in Figure 4.3. The anatomical areas most affected in Paralympic sports (in descending order) include the shoulder, wrist and hand, elbow, knee, ankle, and foot. This pattern of injury is distinct when compared to athletes without impairment, who more commonly experience lower-limb injury. Thus, injury-prevention programs in Paralympic athletes should be sport and impairment specific, but predominantly targeted at preventing injury of the upper limbs.

**Clinically important facts regarding injury in summer Paralympic sports**

While a detailed analysis of all injury findings from the Paralympic Injury and Illness Surveillance Study is beyond the scope of this chapter, the following are other clinically important data to emerge from the study to date:

- Male and female Paralympic athletes have similar injury rates.
- Overall injury rates are similar in the pre-competition and competition periods, although higher pre-competition injury rates are documented in female Paralympic athletes. This may be due to ongoing discriminatory attitudes leading to female athletes having lower access to sports medicine services in their home environments, with higher risk for developing chronic injuries that are not addressed until the time of the Games.
- A little more than 50% of all injuries seen at the Summer Paralympic Games are new-onset acute injuries, and most involve strains and sprains.
Figure 4.3 Percentage of injuries per anatomical region at the London 2012 Summer Paralympic Games. Adapted from Willick 2013. Reproduced with permission from BMJ.

However, it is fortunate that most are not time-loss injuries.

- Powerlifting, judo, goalball, and wheelchair basketball are the sports that place athletes at highest risk of upper-limb injuries.
- Older athletes and athletes with spinal cord injuries are especially at increased risk for upper-limb injuries.
- Ambulant athletics (track and field) athletes are particularly at risk for lower-extremity injury, although athletes with cerebral palsy (CP) may be at decreased risk compared to athletes from other ambulant impairment categories. When comparing impairment groups, it is noted that athletes with CP are likely to have an increase in muscle tone that may prohibit full, forceful lower-extremity eccentric muscle contraction during sprints and distance running events. This physiological difference may in fact be protective against lower-extremity injury, although further studies are needed to determine the full nature of these biomechanical changes (see Figure 4.4).
- Among wheelchair/seated athletes in athletics (track and field), those involved in throwing are at particularly high risk for shoulder injury. Wheelchair/seated athletes typically lack function in the legs and core, which are known to be important power generators in explosive throwing events. Thus, the upper extremity may be subject to increased forces throughout the throwing mechanism.
- A clinician traveling to a 10-day event with 100 Paralympic athletes can anticipate seeing approximately 12–13 injuries, about half of which will be new-onset, acute injuries. If the team composition includes athletes participating in the higher-risk sports listed earlier, it is likely that the team will incur more than 12–13 injuries. Injury risk may also be influenced by environmental conditions such as playing surface and weather.
- A clinician with a Paralympic team should be prepared to diagnose and treat a high percentage of upper-limb injuries, depending on the athletes’ impairment type.
In athletics, lower-extremity injury rates are lower for athletes with cerebral palsy, possibly due to increased muscle tone, which prevents forceful eccentric contraction. Reproduced with permission of Martin Nauclér.

**Coach’s Corner**

Ice sledge hockey and alpine ski have the highest proportion of injury among Paralympic winter sports. For these events, coaches should be sure to work closely with their team medical staff in the event of acute, traumatic injury.

**Paralympic Injury and Illness Surveillance Study: Winter sports**

Injury surveillance was conducted at the 2002, 2006, 2010, and 2014 Winter Paralympic Games. Although injury incidence rates/1,000 athlete days were not reported as with the Injury and Illness Surveillance Study involving summer sports, it is clear from prior research that the incidence proportion (percentage of athletes injured) is higher in some winter sports when compared to summer sports. Indeed, at the Vancouver 2010 Winter Paralympic Games, injuries were reported in 24% of all athletes (Webborn et al., 2012). The proportion of injury was highest in ice sledge hockey (34% of athletes) and alpine ski (22% of athletes).

At the time of writing, the results of the Sochi 2014 Winter Paralympic Games Injury and Illness Surveillance Study have not yet been published. However, preliminary analysis of the data suggests that the observation of alpine skiing and ice sledge hockey as sports with high risk of injury was also evident in Sochi.

**Clinically important facts regarding injury in winter Paralympic sports**

The following are additional key findings that have been reported from injury surveillance of the 2002–14 Paralympic Winter Games. Knowledge of these clinically important injury trends may assist team medical personnel in planning for coverage of winter para-sport events.
The sport of alpine ski has a higher incidence rate of acute injury due to the risk of high-speed trauma. Reproduced with permission of Karl Nilsson.

- Nordic skiing and wheelchair curling have a low injury risk. Although nordic skiing is a sport with heavy use of upper extremities, the nature of propulsion is unique in that it heavily involves scapular retraction with engagement of the latissimus dorsi and lower trapezius, unlike wheelchair court sports that predominantly activate the anterior chest. For athletes who are wheelchair users as a baseline, this activation of the antagonist musculature in nordic skiing may be protective against injury.
- Contusions, fractures, and concussion are more prevalent in winter sports than in summer sports, likely due to a greater potential for high-speed impact in winter sports such as alpine skiing and ice sledge hockey (see Figure 4.5).
- Prevention strategies can be effective. Lower-limb injuries in ice sledge hockey have been reduced following the introduction of protective equipment and regulations regarding sledge height.

**Paralympic Games illness epidemiology**

Until 2012, there were very few studies describing the incidence of illness in athletes with impairment. The London 2012 Paralympic Games Injury and Illness Surveillance Study provided the first detailed record of illness epidemiology in this setting.

The incidence rate of illness was 13.2 illnesses/1,000 athlete days (Schwellnus et al., 2013). As in the case of injury, there was a varying incidence of illness in different sports (see Figure 4.6). Sports with the highest rates of illness included equestrian, powerlifting, table tennis, road cycling, and wheelchair tennis. In some of these sports, the average age of participating athletes is higher. This may increase the risk of overall systemic illness within that sport. The incidence proportion of illness in each system is shown in Figure 4.7. The highest proportion of illness involved the respiratory system, followed by the skin, digestive, nervous, and genitourinary systems. This pattern largely mirrors the pattern of illness observed in Olympic athletes, with the exception of illnesses involving the genitourinary system, which disproportionately affect Paralympic athletes. This is likely due to the high prevalence of neurological injury as a cause of impairment in Paralympians, with the resultant neurogenic bladder and the need for self-catheterization.

**Coach’s Corner**

Illness involving the genitourinary system, for example urinary tract infection (UTI), affects Paralympic athletes more commonly than Olympic athletes. If an athlete develops symptoms of a UTI, they should be diagnosed and treated rapidly to minimize the impact on sports performance.
Wheelchair tennis  
Wheelchair rugby  
Wheelchair fencing  
Wheelchair basketball  
Sitting volleyball  
Table tennis  
Swimming  
Shooting  
Sailing  
Rowing  
Powerlifting  
Judo  
Goalball  
Football 7  
Football 5  
Equestrian  
Cycling road  
Athletics  
Boccia  
Cycling track  
Archery

Figure 4.6  Illnesses per 1000 athlete-days at the London 2012 Summer Paralympic Games. Adapted from Schwellnus 2013. Reproduced with permission from BMJ.

Other  
Haematological  
Circulatory  
Specific sports related conditions  
Behavioural  
Endocrine  
Eye and adnexa  
Ears and mastoid  
Genitourinary  
Nervous system  
Digestive  
Skin and subcutaneous  
Respiratory

Figure 4.7  Percentage of illnesses per system at the London 2012 Summer Paralympic Games. Adapted from Schwellnus 2013. Reproduced with permission from BMJ.
Clinically important facts regarding illness in Paralympic sports

Awareness of a few high-yield facts can assist team medical staff in planning for and preventing illness in Paralympic athletes. The following are additional clinically important findings reported from the London 2012 Paralympic Games Injury and Illness Surveillance Study:

- Illness is common in Paralympic athletes, and the incidence proportion of illness is higher at the Paralympic Games (14.2%) compared to the Olympic Games (6.7–12.1%; Schwellnus et al., 2013). Direct comparison of these figures should be interpreted cautiously given that prior studies of Olympic athletes did not include exposure data, thus these numbers do not account for events of varied duration. At the Summer Paralympic Games, the incidence rate of illness in the pre-competition period was similar to that in the competition period.
- Risk factor modeling has shown that there is a significantly higher incidence of illness in equestrian compared with other sports. However, age and gender are not independent predictors of illness.
- Most illnesses were due to infections. For example, 50% of all respiratory illnesses, 44% of skin and subcutaneous tissue illnesses, and over 82% of genitourinary illnesses were deemed to be due to infection. Environmental conditions (including allergens and environmental pollution) were reported to account for 30% of respiratory conditions, 37% of ear and mastoid illnesses, 32% of nervous system conditions, and 26% of digestive system illnesses.
- Skin and subcutaneous tissue infections were most common in the group of athletes with spinal cord injury, amputation/limb deficiency, and cerebral palsy. Reasons to explain the higher incidence of skin infections include loss of sensation and prolonged contact pressure in athletes using wheelchairs.
- The stump–socket interface is also a high-risk area in athletes with amputation, as this area is subject to high forces, hot/moist conditions, sweating during exercise, and possible bacterial contamination in the sport setting.
- Over 75% of urinary tract infections occurred in the group of athletes with spinal cord injury. It is well established that individuals with spinal cord injuries are more susceptible to urinary tract infection due to a variety of factors, including neurogenic bladder and prolonged or intermittent urinary catheter use.
- The most common primary or secondary symptoms of illnesses were pain (29%), followed by a sore throat (19%) and cough (13%). It is of interest that skin breakdown accounted for only 5% of all primary symptoms and bladder symptomatology accounted for only 4% of all primary symptoms. This may be due to the inability of some athletes with spinal cord injury to feel pain and bladder symptomatology in the lower body, thus reporting more general, systemic issues such as fatigue, fever, or increase in spasms as their primary symptoms.
- Although most illnesses were not time-loss illnesses, nearly 1 in 5 illnesses resulted in one or more days lost.
- Team medical staff should be aware that in many cases of reported infection, symptoms were already present the day before the athlete reported for care. A delay in reporting of symptoms of more than 24 hours could have important clinical implications in an athlete’s medical care, as it is during this period when athletes are more likely to be contagious.

Illness data were also collected during the 2014 Sochi Paralympic Games, and once published will add to the understanding of illness during the Winter Games. Illness and injury surveillance remains an important mainstay of athlete care and forms an integral part of the formulation of prevention programs.

Sudden cardiac death and pre-participation cardiac screening

It is well known that regular aerobic exercise reduces the risk of cardiovascular disease, in particular acute myocardial infarction and sudden cardiac death (SCD). On the other hand, strenuous exercise may increase the risk of acute coronary events and sudden cardiac arrest in certain individuals who are particularly susceptible. Over the past two decades there has been growing knowledge about the risk of SCD associated with exercise in young athletes. The risk of SCD in athletes less
than 35 years of age is about 1–3/100,000 athletes. SCD generally increases with age and is more likely to occur in men. In healthy adults over the age of 35 years who are active joggers or marathon runners, the estimated rate of SCD varies from 1/15,000 to 1/50,000. Thus, SCD in the athlete is a rare event, but each occurrence is a tragedy. Although SCD in the athlete may never be eradicated, the sports medicine community, in collaboration with sports federations and event organizers, has an obligation to reduce its risk to an absolute minimum. In Paralympic sports, there is very limited knowledge about the occurrence of SCD and how this may vary in comparison to athletes with no impairment. Thus, there is a need for studies in this field as well as the implementation of pre-participation cardiac screening programs.

**Coach’s Corner**

Pre-participation cardiac screening of individuals who are engaged in sports is recommended in many countries to identify athletes who are at risk of developing sudden cardiac death.

It is now known that SCD during exercise or sports is caused by an abrupt ventricular tachyarrhythmia due to an underlying cardiovascular disease. In younger athletes, the most common causes of SCD are genetic or congenital cardiovascular abnormalities, including cardiomyopathies and coronary artery anomalies. One of the most common is hypertrophic cardiomyopathy (HCM), reported to account for more than one-third of all SCD. This is an inherited condition in which the walls of the heart are enlarged and the muscle fibers in the heart become disorganized. Cardiomyopathy affecting heart rhythm is another common cause of SCD in younger athletes, whereas atherosclerotic coronary artery disease is more frequently observed as a cause of SCD in older athletes.

The anatomical and structural variants that place athletes at risk for SCD are most often clinically asymptomatic and very difficult to diagnose. Therefore, systematic screening of all individuals engaged in sports has the potential to identify athletes who are at risk and thereby to reduce mortality by appropriate preventive interventions. With the growing awareness of SCD in athletes, systematic pre-participation screening programs have been in place for several decades in some world regions. For example, Corrado et al. (2006) reported that due to a particularly high prevalence of a rare cardiomyopathy resulting in SCD in the Veneto region of Italy, a screening program has been in place for 25 years. With this program, annual rates of SCD among competitive athletes 12–35 years of age were reduced by 89%.

The European Society of Cardiology Section of Sports Cardiology screening program is now commonly implemented across the world (Corrado et al., 2005). This screening program is supported by the International Olympic Committee (IOC) as part of the Periodic Health Evaluation (IOC, 2009). It comprises three parts: a family and personal history of cardiovascular diseases or symptoms, a physical examination, and a 12-lead electrocardiogram (ECG). In case of positive findings at the initial evaluation, additional tests are typically requested. Athletes who are found to have a cardiovascular condition placing them at risk for SCD should be managed according to the available recommendations for sports eligibility in their discipline.

Screening is recommended to start at the beginning of competitive athletic activity, usually between the ages of 12 and 14 years, and repeated in teenagers on a regular basis, at least every two years. It is also recommended that all athletes who train and compete in high-intensity aerobic sports resulting in near maximal cardiovascular effort undergo this screening program.

Many countries and international organizations have advocated or made mandatory such pre-participation screening in young athletes. There is, however, an ongoing debate among cardiologists about the efficacy of cardiac screening, the impact of false-positive results, and the cost-effectiveness of routine pre-participation cardiovascular evaluation (Corrado et al., 2011).

**Head injuries and concussion in sports**

Head injuries resulting in a concussion are common in sports and are of great concern to athletes, coaches, team medical staff, and sports
organizations. Head injuries and concussion are particularly common in team contact sports such as ice hockey, football, and soccer, but can also occur in individual sports, for example downhill skiing. In Paralympic sports, head injuries and concussion have been reported in ice sledge hockey, football 5-a-side (for athletes with visual impairment), and downhill skiing. Because most of these reports are anecdotal, there is a need for more detailed epidemiological data on head injuries and concussion in Paralympic sports.

Coach's Corner
An athlete who has experienced a concussion should always be removed from the field of play and assessed by a medical professional before returning to play.

A concussion is an injury to the brain that leads to a temporary loss of brain function. The most common symptoms are headache, dizziness, loss of balance and coordination, loss of concentration, memory disturbances, disorientation, and confusion. A majority of concussions do not lead to a loss of consciousness.

If an athlete is suspected to have experienced a concussion, he or she should always be removed from the field of play and assessed by a medical professional. If a serious head injury occurs, the initial management includes the ABCs of life support (airway, breathing, and circulation). Additionally, it is always important to rule out a neck or spine injury. In case of a period of unconsciousness, prolonged loss of memory after the injury (post-traumatic amnesia), or any signs of deterioration, the athlete should be referred to a nearby hospital for further examination. Usually, a computed tomography (CT) scan of the head is performed to rule out any major intracranial injuries. The athlete should then be monitored for as long as needed to identify or rule out any major complications.

A standardized tool for evaluating injured athletes for concussion, the SCAT3 (Sport Concussion Assessment Tool, 3rd Edition), has been developed by a group of international experts (McCrory et al., 2013). The SCAT3 is designed for use by medical professionals and includes several sections that comprehensively assess an athlete when a concussion is suspected, while also assisting in measuring recovery. In Paralympic athletes, certain portions of the SCAT3 assessment may require adaptation. For example, an athlete with lower-extremity impairment who experiences a head injury playing wheelchair basketball may not be able to complete Modified Balance Error Scoring System (BESS) testing, which evaluates balance while in a standing position. Looking forward, further guidelines are needed to provide clinicians with evidence-based recommendations for concussion evaluation in these athletes.

As long as the athlete perceives symptoms of a concussion, he or she should not return to play. Since balance and coordination are impaired, the athlete could sustain injuries to other parts of the body or another head injury, the latter of which may lead to a Second Impact Syndrome (SIS). Although its mechanism is poorly understood, SIS may lead to fatal brain swelling that occurs when a second concussion is sustained before complete recovery from an initial injury.

Full recovery after a concussion can vary in timing and duration. In the majority of cases, the athlete will be fully recovered within six to ten days and can successfully return to competition. In a few cases, symptoms may persist for several weeks or months. This is referred to as post-concussive syndrome, and may include symptoms such as memory and concentration problems, mood swings, personality changes, headache, fatigue, dizziness, insomnia, and excessive drowsiness. If the athlete remains symptomatic for more than ten days, consultation by a medical practitioner with experience in the management of sports concussion is recommended. Athletes who sustain repeated concussions are at risk of experiencing accumulated post-concussive symptoms and should consider ending sports participation permanently. Accumulated symptoms may lead to a progressive cognitive decline, as well as personality changes and emotional symptoms.

Before returning to full play, every athlete should follow a stepwise, supervised recovery program involving stages of progression (see Table 4.1). The first step is complete rest, during which the athlete should avoid physical exertion and also other activities that involve brain stimulation (for
Chapter 4

Table 4.1  Return to play after concussion.

Athletes should not be returned to play the same day of injury. When returning athletes to play, they should be medically cleared and then follow a stepwise supervised program, with stages of progression; examples of such a program are presented here.

<table>
<thead>
<tr>
<th>Rehabilitation stage</th>
<th>Functional exercise at each stage of rehabilitation</th>
<th>Objective of each stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No activity</td>
<td>Physical and cognitive rest</td>
<td>Recovery</td>
</tr>
<tr>
<td>Light aerobic exercise</td>
<td>Walking, swimming, or stationary cycling, keeping intensity at 70% of maximum predicted heart rate. No resistance training</td>
<td>Increase heart rate</td>
</tr>
<tr>
<td>Sport-specific exercise</td>
<td>Skating drills in ice hockey, running drills in soccer. No head-impact activities</td>
<td>Add movement</td>
</tr>
<tr>
<td>Non-contact training drills</td>
<td>Progression to more complex training drills, e.g., passing drills in football and ice hockey. May start progressive resistance training</td>
<td>Exercise, coordination, and cognitive load</td>
</tr>
<tr>
<td>Full contact practice</td>
<td>Following medical clearance, participate in normal training activities</td>
<td>Restore confidence and assess functional skills by coaching staff</td>
</tr>
<tr>
<td>Return to play</td>
<td>Normal game play</td>
<td></td>
</tr>
</tbody>
</table>

There should be at least 24 hours (or longer) for each stage and if symptoms recur the athlete should rest until they resolve once again and then resume the program at the previous asymptomatic stage. Resistance training should only be added in the later stages.

Source: Adapted from the International Consensus Statement on Concussion in Sport, at the 4th International Conference on Concussion in Sport held in Zurich, November 2012.

example reading, computer use, phone use, social media). This usually takes one to three days and should result in a return to the athlete’s prior baseline level of cognition when at rest. The next step includes light aerobic exercise, such as walking or stationary cycling, but no resistance training. Thereafter, some sports-specific exercise and the progressive addition of strength training can be introduced. The fourth step includes non-contact sports-specific activities. In the fifth step the athlete can resume full contact practice after medical clearance if he or she does not have any recurrence or signs of symptoms of concussion. Finally, the athlete can be cleared to return to full competitive play. If concussion symptoms recur at any step, the athlete should revert to the previous asymptomatic stage and resume the progression after an additional 24 hours. These guidelines allow for a more individualized approach when returning athletes to competition from concussion, allowing them to recover at their own individual rates.

Medications that may have an impact on performance

The pharmacological management of illness and injury in athletes involves unique considerations when compared to the general population. Indeed, many medications may be appropriately indicated to treat underlying medical conditions or sports-specific medical concerns, such as exercise-induced asthma. However, when treating athletes, clinicians must closely consider the interaction between a medication’s pharmacokinetics and the athlete’s physiology, noting how this may affect performance. Additionally, some classes of medications may be used more frequently by athletes with impairment and deserve special attention.

Anti-doping and Therapeutic Use Exemption considerations

Paralympic athletes engaged in national and international competitions are typically subject to testing for prohibited substances and methods under the guidelines of the World Anti-Doping Agency (WADA) Code and the IPC Anti-Doping Code. This may include both in-competition and out-of-competition testing, involving the collection of blood and/or urine samples by certified doping control officers (DCOs). Special investigations may also be performed in cases where suspicious behavior is identified on the part of athletes, trainers, coaches, or team medical personnel. For more information regarding the International
Paralympic Committee’s anti-doping program, see http://www.paralympic.org/antidoping.

**Coach’s Corner**

When treating athletes, clinicians must closely consider the interaction between a medication's pharmacokinetics and the athlete's physiology, as well as the use of prohibited substances and the need for Therapeutic Use Exemption.

Under the auspices of the Code, certain classes of medications and methods that have the potential for performance enhancement are deemed prohibited and are thus included on the WADA Prohibited List, which is updated annually. Athletes who are found to be utilizing these prohibited substances may be subject to sanctions. At times, however, athletes may require medications that are included on the Prohibited List for reasons that are medically valid. In these cases, the athlete must apply for a Therapeutic Use Exemption (TUE). This is accomplished by gathering the athlete’s medical records and results of diagnostic testing, as well as submitting a formal application to the national, federation, or major event TUE Committee that holds jurisdiction at the time of application. On review, a TUE will only be approved if it meets all of the criteria under the WADA International Standard for Therapeutic Use Exemptions (ISTUE). More information regarding the ISTUE can be found at https://www.wada-ama.org/en/what-we-do/international-standards.

For a summary of medications that may be frequently used by athletes with impairment and whether or not a TUE is required, see the following section. For medications not included on this list, it is best to contact your national or federation anti-doping agency for further information. Additionally, for athletes in certain geographical regions, the Global DRO website can provide an excellent resource for looking up whether a medication is prohibited in competition or out of competition in various sports; this can be found at http://www.globaldro.com/us-en/. As already mentioned, the WADA Prohibited List is updated on an annual basis. The information presented here is valid for calendar year 2015, and may be subject to change in subsequent years.

**Major categories of medications frequently used by athletes with impairment**

Athletes with impairment are more likely to use certain classes of medications for the treatment of underlying medical conditions that require long-term management. In Table 4.2, a brief description of these medications is provided, with a note of any performance-specific considerations to bear in mind for use in an athlete population. It should be noted that this list is not comprehensive. It offers high-yield examples of frequently encountered medications. Further information is also in the IOC Handbook of Sports Medicine and Science, *The Paralympic Athlete*, Chapter 10, pp. 185–188.

**Travel and environmental considerations**

Long-distance travel has become increasingly common for athletes with impairment, and can carry additional risks to athletes’ health and performance. Therefore, athletes, their trainers, and coaches need to understand the challenges of long-distance travel, while also taking certain precautions and developing suitable strategies when traveling for training or competition.

**Planning for travel**

Careful preparation and planning for travel may limit potential risk factors and ensure that athletes arrive in the best condition to perform optimally. Before travel, it is imperative to have as much knowledge as possible about the destination country, environmental conditions, accommodation, and what food may be available. In addition, it is important to know what level of support will be available to the athlete and team on arrival. In advance of finalizing travel plans, it is advisable to discuss with the airline what accommodations will be in place for passengers with impairment, and if any specific regulations and cost apply to the transport of personal equipment, such as wheelchairs and/or sports equipment.
Table 4.2 Medications commonly used by Paralympic athletes.

<table>
<thead>
<tr>
<th>Medication</th>
<th>Common condition(s) treated</th>
<th>Potential adverse side effects</th>
<th>TUE requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anti-spasticity medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baclofen</td>
<td>Spasms and increased muscle tone</td>
<td>Fatigue, sedation</td>
<td>NO</td>
</tr>
<tr>
<td>Tizanidine</td>
<td>Spasms and increased muscle tone</td>
<td>Fatigue, sedation</td>
<td>NO</td>
</tr>
<tr>
<td>Botulinum toxin injection</td>
<td>Spasms and increased muscle tone</td>
<td>Skeletal muscle weakness</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Analgesic medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-steroidal anti-inflammatories</td>
<td>Soft tissue inflammation</td>
<td>Gastrointestinal bleeding or reflux, renal</td>
<td>NO</td>
</tr>
<tr>
<td>Gabapentin</td>
<td>Neuropathic pain after neurological injury</td>
<td>Fatigue, sedation, weight gain</td>
<td>NO</td>
</tr>
<tr>
<td>Glucocorticoids</td>
<td>Systemic inflammation, autoimmune</td>
<td>Flushing, insomnia, anxiety, elevated blood</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>conditions</td>
<td>sugars, infection</td>
<td></td>
</tr>
<tr>
<td>Opiates</td>
<td>Severe pain</td>
<td>Fatigue, sedation, constipation, pruritus</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Erectile dysfunction medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sildenafil</td>
<td>Erectile dysfunction due to neurological injury</td>
<td>Headache, dizziness, flushing, visual disturbance</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Psychotropic medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methylphenidate (Ritalin)</td>
<td>Attention deficit hyperactivity disorder</td>
<td>Fast heart rate, palpitations, decreased</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>appetite</td>
<td></td>
</tr>
<tr>
<td><strong>Cardiovascular medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta-blockers</td>
<td>Hypertension, tachycardia, tremor,</td>
<td>Low blood pressure, slow heart rate,</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>anxiety</td>
<td>dizziness, fatigue</td>
<td></td>
</tr>
<tr>
<td>Diuretics</td>
<td>Fluid retention, heart failure</td>
<td>Dehydration, renal dysfunction,</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>electrolyte imbalance</td>
<td></td>
</tr>
<tr>
<td><strong>Respiratory medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta-agonists</td>
<td>Asthma, reactive airway disease</td>
<td>Tachycardia, anxiety, tremor, increased</td>
<td>YES**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>blood sugar, nausea</td>
<td></td>
</tr>
</tbody>
</table>

* Therapeutic Use Exemption (TUE) requirement as of April 2015, which may be subject to change.
† TUE for glucocorticoids required for oral, intravenous, or intramuscular dosing.
‡ TUE for beta-blockers required for precision sports of archery and shooting – recommended that athletes contact their national or federation anti-doping authority.
∗∗ TUE restrictions are dose dependent for salbutamol, formoterol, and salmeterol.

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**Coach’s Corner**

Careful preparation and planning for travel may limit potential risk factors and ensure that athletes arrive in the best condition to perform optimally. Before travel, it is imperative to have as much knowledge as possible about the destination country, environmental conditions, accommodation, and what food may be available.

Each country may have its own specific public health considerations, including epidemic infectious diseases, immunization requirements, and health insurance regulations. Depending on the destination, the athlete should know well in advance which considerations would apply. There are several websites that provide current information, such as the World Health Organization’s “International Travel and Health,” available at http://www.who.int/ith/en/. Also, the athlete should be aware of which immunizations are required well in advance of travel, as some immunization programs may take several weeks or months to complete.

Athletes should always travel with their own supply of medications for the entire journey, and it is advisable to carry several days' supply in carry-on luggage. Athletes will also need a letter from their treating physician confirming that the medications carried are for personal use. If the athlete uses syringes and needles (e.g., for insulin administration), the letter should include information on the diagnosis and the specific need for these materials. If the athlete uses medications that are on
the WADA Prohibited List and has a valid TUE, he or she should always bring a copy of this when traveling.

Athletes who experience neurogenic bladder also need to carry with them a sufficient supply of catheters, urine-collection bags, and gloves, including some in their carry-on luggage to last for a few days in case travel is delayed. A bag with basic first aid equipment and medications is useful to bring on board for long-haul travel. Finally, a small bottle (less than 100 mL) of hand antiseptic will help the athlete reduce the risk of infections during, for example, meal times and before or after using the restroom.

Safe travel and considerations on arrival

Air travel, including getting on and off an aircraft as well as the time spent en route, may potentially affect an athlete’s health and safety. If an athlete requires assistance to board the aircraft, it is important to make sure that cabin staff are aware of his or her specific needs in order to minimize the likelihood of injury.

Sitting in the same position for long periods, particularly in a small aircraft, can be rather unpleasant. For athletes with insensate (no-sensation) regions, the risk of pressure ulcers increases proportionately with the length of the flight. For athletes who use wheelchairs for daily mobility, it is advisable to take the wheelchair cushion with them on board, thus applying the same precautions as at home. Compression stockings are recommended to reduce lower-extremity swelling and the risk of deep venous thrombosis (DVT). These can be put on before boarding and kept on during the entire flight. If possible, the athlete should get up and move regularly.

In the air-conditioned aircraft cabin there is an increased risk of dehydration. This requires that the athlete maintain a regular fluid intake. It is recommended to avoid alcoholic and caffeinated beverages, as they can increase diuresis and exacerbate dehydration. Food intake during the flight can be a challenge. It is often possible to order special meals (for example vegetarian, Muslim, kosher, or specific dietary meals), which are often distributed before the rest of the meals. Athletes can also bring some familiar items with them, for example healthy snacks and fruit. The change in air pressure during the flight may cause some abdominal discomfort. Athletes who have an increased risk for constipation can prepare themselves for this a few days before departure by adjusting their food intake to avoid it and, preferably, emptying their bowel early and often on the day of travel.

On arrival, it is important to perform key health checks. Athletes can review their hydration status by looking at their urine color and volume. Even if athletes have worn compression stockings during the flight, they may experience lower-extremity swelling. Slightly elevating the legs when sleeping at night or when lying supine may help to reduce this. This may be particularly important for amputee athletes, for whom limb swelling may lead to skin breakdown and/or poor fit of their sports prosthesis. Additionally, amputee athletes who use a non-sports prosthesis during travel may wish to remove the prosthesis for flights of long duration in order to avoid unnecessary pressure and risk of skin problems. For athletes who have sensory deficits, checking the skin at the buttocks, back, or ankles for any signs of pressure ulcers can be done with a small mirror.

Impact of multi-timezone travel

Traveling long distances naturally affects our daily sleep–wake cycle and leads to sleep loss and tiredness. Adapting to new timezones and overcoming jet lag takes time, but can be facilitated by careful planning. It is generally believed that it takes about one day for each timezone crossed to adapt to a normal sleep–wake pattern. If it is possible to start the shifting of timezones prior to travel, it may help to hasten the athlete’s adaptation on arrival. Minimal exposure to, or restriction of, daylight can partly help to synchronize to local time and overcome jet lag. Melatonin can also be used. Similarly, returning home can be equally strenuous and similar precautions and strategies should be considered.

It is recommended to change clocks to the new timezone when boarding an aircraft. This will help the athlete to adapt to the new timezone by changing meal types and times, sleeping at appropriate
intervals, and making sure that medications are taken at the correct times. On arrival, it is important to avoid daytime naps and to go to sleep on time in order to normalize the sleep-wake cycle, and also to adapt meal types and times as much as possible to the local timezone. One important thing to remember is that urine production typically reflects a diurnal pattern, meaning that less urine is produced at night. This hormonal mechanism takes several days to adapt, meaning that athletes may initially need to get up at night to empty the bladder.

On arrival, it is advisable that athletes familiarize themselves with the local environment, accommodation, eating places, and climate. This will ensure that adaptations will go smoothly and enable the athlete to start training as soon as possible after arrival.

The potential impact of environmental pollution

As already noted, elite athletes with impairment will frequently travel great distances for training and competition. Additionally, many athletes reside in world regions where environmental pollution is an important consideration for health and performance.

A primary concern for athletes with impairment is the air quality and its effect on multiple systems, predominantly respiratory. For athletes with pre-existing respiratory conditions such as asthma and/or significant allergies, careful monitoring is needed, with adjustment of baseline medication dosing based on the degree of air pollution and the athlete's symptoms. Athletes who are not symptomatic at rest may develop symptoms during maximal exercise, when respiratory exchange and exposure to environmental particulates are highest. For a more comprehensive discussion regarding the mechanisms and pathophysiology of air pollution on the athlete's respiratory system, see the IOC Handbook of Sports Medicine and Science, *The Paralympic Athlete*, Chapter 12, pp. 222–225.

Issues related to water and food contamination also may become relevant during travel to certain world regions. In these cases, collaboration with event organizers is imperative to ensure an adequate supply of safe drinking water and appropriate foods to meet athletes’ needs. The use of bottled, purified water for daily consumption is advised, including during daily hygiene (e.g., teeth brushing). For all athletes, minimizing direct contact with environmental pollutants can be optimized through the aggressive promotion of hand washing, and ensuring appropriate disposal of needles and contaminated substances within the athlete's living, training, and competition environments.

Accessibility of the built environment: Impact on athletes with impairment

The interaction of athletes with their environment and its accessibility are unique and prominent considerations for athletes with impairment, and they certainly have the potential to have an impact on an athlete’s health and performance. For athletes with varied types of impairments, different barriers may pose challenges. For example, for an athlete who is a wheelchair user due to cervical spinal cord injury, lack of fully accessible toilets may pose a concern from the standpoint of timely bowel and bladder evacuation, leading to increased likelihood of urinary tract infection, while also putting the athlete at risk of autonomic dysreflexia. For an athlete with visual impairment, lack of accessibility in way finding may lead to delays in the athlete receiving appropriate clinical care after experiencing an acute injury on the field of play. On arrival at the Athletes’ Village in a Paralympic Games environment, amputee athletes may be subject to walking much longer daily distances than they are typically accustomed to, leading to skin breakdown or other problems at the stump-socket interface.

For this reason, coaches, trainers, and sports medicine practitioners must take care to evaluate and survey the environment in advance of the athlete’s arrival, and work as a team to mitigate any accessibility concerns. This evaluation should include all phases of the athlete’s experience, to include air and ground transportation, lodging, training facilities, and field of play. Of course, it is essential that all team staff work in concert with event organizers to ensure that accessibility remains a priority throughout the planning and implementation process.
In light of this interaction between the accessibility of the environment and athletes’ health, sports medicine practitioners must also become advocates to promote the ultimate well-being, and thus performance, of their athletes. In keeping with this vision, the International Paralympic Committee Strategic Plan 2011–2014 (IPC, 2011) notes that the organization’s strategic goals are to “contribute to the overall aspiration of creating a more equitable society through the example of Paralympic sports and its athlete ambassadors.”

Sports nutrition

Eating well is imperative for good health. For a Paralympic athlete it can also have a significant impact on sports performance. It is therefore of central importance that all athletes learn how to plan their meal and fluid intake, and for them to have a clear nutritional strategy before, during, and after training and competition.

Coach’s Corner

Athletes should learn how to plan their caloric and fluid intake, and to have a clear nutritional strategy before, during, and after training and competition.

Today, athletes are exposed through the media to a wide variety of dietary trends and recommendations. Many diets are not suited for athletes, however, and could actually be detrimental. Evidence-based guidelines on the amount, composition, and timing of food intake are available, but are predominantly focused on athletes without impairments. Our knowledge in this area has grown rapidly over the past 30 years. Insight into the human body and the association with nutritional aspects enables us to extrapolate recommendations to Paralympic athletes (Broad, 2013).

Increasingly, those involved in high-performance sport are aware of the importance of having a nutritional strategy, and therefore engage sports nutrition experts to assist athletes in training and performing effectively while also preventing injury and illness. Food is also closely linked to our social life and can be a source of enjoyment.

We should therefore see sports nutrition not only as something technical and associated with high performance, but also as a way to engage in a healthy lifestyle that will continue for years after an athlete’s competitive career has finished.

Energy needs

An athlete’s daily energy requirements are dependent on the resting metabolic rate (RMR), including energy expenditure during basic physiological functions, such as cellular maintenance, thermoregulation, growth, reproduction, and immunity, non-exercise activity thermogenesis (NEAT), energy expenditure during exercise, and diet-induced thermogenesis (DIT). RMR is mainly determined by fat-free mass, but is also affected by energy balance and comprises 55–65% of the total energy expenditure in normal sedentary people. The amount of exercise, in terms of its intensity, duration, and frequency, is the most variable component of total energy expenditure and increases total energy expenditure per se. Highly trained endurance athletes who are in energy balance have been reported to have elevated RMR post-exercise that can be maintained for at least 39 hours after the last training session, while female athletes with menstrual dysfunction have been reported to have lower RMR compared to eumenorrheic athletes. Energy balance exists when daily intake of food (carbohydrates, fat, and proteins) equals energy expenditure.

To enhance our focus on and understanding of an athlete’s energy needs, a new concept – energy availability – has been defined. This refers to the energy that is available for all physiological functions after the expenditure of energy on exercise has been deducted from the daily energy intake. It has become increasingly apparent that health and performance problems among able-bodied athletes, both female and male, can be caused by low energy availability. Therefore, the term “Relative Energy Deficiency in Sport” (RED-S) has been defined. Female athletes may show clinical signs of an altered menstrual function, while reduced bone health has been reported in both female and male athletes from weight-sensitive sports. In all athletes, low energy availability can compromise immunity,
lead to poor hormonal function, and ultimately affect bone as well as cardiovascular health. Our knowledge of RED-S in Paralympic athletes is, however, very limited and further studies in this field are clearly needed.

To ensure early detection of athletes at risk for RED-S, annual screening is recommended. By developing suitable nutritional strategies, an athlete, together with his or her trainer and team medical staff, can prevent RED-S. This can be achieved by keeping several concepts in mind. Energy needs are affected when an athlete changes the type and amount of training. Also, when traveling or if there is a change in the daily routine, it is important to be aware of the need to re-establish food intake and meal patterns. For Paralympic athletes, this can be somewhat problematic and may require more in-depth planning. For example, it may be difficult to calculate habitual exercise-based energy demands due to changes in weekly training. Additionally, changes in day-to-day life linked to the athlete’s impairment, such as an increase in spasticity and/or gait disturbance, may affect the athlete’s metabolic requirements and ability to eat.

Moreover, assessing lean body mass in athletes with certain impairments such as spinal cord injury is not straightforward due to a lack of validated methods. A slightly increased drive to lose or maintain a low body weight is associated with dietary characteristics likely to increase the risk for low energy availability and RED-S. Handling the issue of leanness and body weight with care is therefore paramount in sport environments. An athlete who needs to lose weight should be provided with professional counseling, ensuring a time-limited nutritional treatment plan with proper and effective guidelines for weight loss that ends with re-establishing optimal energy availability and weight stability. It is thus important that coaches and medical staff members are educated regarding the concept of low energy availability and RED-S to ensure prevention, early detection, and treatment.

**Carbohydrates for training and competition**

Carbohydrates account for over 50% of our total energy intake, regardless of our degree of physical activity. Additionally, despite current dietary trends, carbohydrates are still an athlete’s main source of muscle fuel during exercise. Carbohydrates are also necessary for the maintenance of brain function during exercise. It is well known that low levels of carbohydrates can lead to central and well as peripheral muscle fatigue, and have a negative impact on performance. Athletes therefore need to develop strategies to ensure an adequate intake of carbohydrates before, during, and after training and competition. As each athlete’s needs may vary due to differences in the type and volume of training, athletes must learn how to balance their intake of carbohydrates.

Currently, there is a great variety of carbohydrate-containing products on the market. The most common and available carbohydrate-rich foods are bread, pasta, rice, cereals, and dried fruit. The amount of carbohydrate needed for any athlete is based on their type of training and is defined as grams relative to the athlete’s body mass. With a light training load (low-intensity or skill-based activities), about 3–5 g/kg of an athlete’s body mass per day is considered optimal. During high training loads, with moderate- to high-intensity exercise for several hours per day, an athlete may need up to 8–12 g/kg of body mass in order to meet energy requirements.

As carbohydrates are our main source of energy but subject to limited storage abilities, it is important to refuel muscles after an intensive training session. Consuming carbohydrate-rich foods and drinks soon after training, targeting an intake of about 3–5 g/kg of the athlete’s body mass per hour for the first four hours, will help with rapid refueling. The combination of carbohydrates and protein available in many of the food and beverage products used after training is considered to enhance recovery by promoting higher rates of glycogen storage than carbohydrates alone. Examples of nutrient-rich carbohydrate and protein combinations that are readily available for most athletes include options such as breakfast cereal and low-fat milk, a fruit-flavored dairy-based smoothie, or a sandwich with chicken fillet.

High-intensity sports activities lasting longer than one hour can cause a depletion of carbohydrate stores and lead to physical as well as mental
fatigue. Intake of sufficient carbohydrates prior to the event can prolong performance and delay the onset of fatigue. Typically, an athlete can normalize muscle glycogen stores within 24 hours with a carbohydrate-rich diet. Similarly, regular, albeit small, intake during the event will also enhance performance. A range of carbohydrate-rich products such as sports drinks, bars, and gels are available. Many athletes develop specific tastes and likenings, and as long as the amount of carbohydrate is adequate, the exact type of food is generally less important.

**Protein requirements**

Protein comprises amino acids, which are important building blocks for repairing damaged tissue, including skeletal muscle. Amino acids are also the base for the creation of hormones and enzymes. It is therefore important that our food intake contains adequate amounts of protein. For many years it has been debated whether athletes need a higher amount of protein when compared to the non-exercising general population. Currently, it is generally supported that protein intake for both strength and endurance athletes should be 1.2–1.6 g/kg of the athlete’s body mass per day. This requirement is typically met very easily through a standard, non-vegetarian diet, and very few athletes need protein supplements in order to reach even the upper levels of the protein recommendations.

To optimize post-exercise muscle protein synthesis, the timing of the intake of protein is important. Eating about 20–25 g of high-quality animal protein (e.g., dairy products, meat, eggs) soon after exercise is considered optimal in promoting muscle protein synthesis. Dairy products, such as milk and yoghurt, are a practical and valuable source of protein. They can be combined with whey protein (such as milk powder) and fruit or berries (e.g., banana and blueberries) to make a protein-rich drink that is rapidly digested after exercise. As little as 300 mL of regular cow’s milk combined with 20 g (2–3 tablespoons) of fat-free milk powder gives 20 g of high-quality protein, plus a number of other important nutrients (vitamins and minerals).

Human skeletal muscle is stimulated to increase its protein synthesis for up to 24 hours after exercise. It may therefore be advantageous to spread daily protein intake over the meals consumed during a day. Instead of eating a few larger meals containing protein, several smaller meals containing protein can be planned. It is also worth mentioning that a well-planned vegetarian diet can meet the athlete’s need for protein. Beans, peas, lentils, nuts, seeds, cereal, soy protein in the form of tofu, and mycoprotein in the form of Quorn™ are all protein-rich vegetarian foods.

**Hydration for training, competition, and recovery**

Developing a plan for drinking enough fluid before, during, and after exercise is as important as eating well. Dehydration can have an impact on performance, and as every athlete is unique, his or her drinking habits should always be tailored to the individual’s needs. It is therefore helpful to learn when, what, and how much to drink far in advance of the athlete’s competition (see Figure 4.8).

Normally, an athlete may not need to drink if the competition event or training session lasts less than about 30 minutes. Additionally, an athlete can hydrate well before the start. The athlete should develop a rehydration plan to keep fluid deficit to less than 2% of body weight. In a hot, humid climate, the rate of sweat loss increases and athletes need to be more cautious about rehydration. Additionally, athletes with certain impairments may need to adjust their rehydration plan. For example, athletes with spinal cord injury may have an impaired ability to sweat below their level of injury. This must be taken into account when planning for rehydration. An alternative to drinking excessive fluid is to cool the body with ice-cold towels. Water is by far the best fluid to use for hydration. During competition or when training with high intensity for more than 60 minutes, and especially with two training sessions per day, it is recommended to add some form of carbohydrate. Sports drinks typically have a carbohydrate content of 4–8 g per 100 mL fluid. In most cases this is a practical, rapid energy source to meet the athlete’s needs. Practicing a hydration plan and testing different fluids (commercial and non-commercial) is part of successful preparation for an event. Commercial
sports drinks contain sodium, which is needed for an optimal absorption of fluid in the intestine. Some athletes also find caffeine beneficial and at times will add some at a later stage of their exercise in order to counteract fatigue. Caffeine (about 2–3 mg/kg body weight, equivalent to about 100–200 mg) can enhance performance during a prolonged event. This is equivalent to one cup of brewed coffee.

Hydration after training or competition is equally important to restore fluid losses. It is recommended that an athlete needs to drink about 1.5 liters of fluid for every kilogram of weight loss during training or competition. As sweating is highly individual, it is advised that athletes learn how much they lose during a regular training session. Measuring body weight before and after a normal session and calculating the fluid deficit (taking into account fluid intake) will teach the athlete how much fluid he or she needs to drink under normal circumstances.

Vitamins and minerals

Both vitamins and minerals are important for athletes. Among other things, they act as co-factors in metabolism as well as being antioxidants. Additionally, certain vitamins and minerals are necessary for building up tissues (e.g., calcium in bones). In general, a well-planned diet with an adequate energy intake will meet an athlete’s demands for vitamins and minerals. Therefore, athletes rarely need to take vitamin and mineral supplements. Other factors such as a restricted diet as a vegan, low-carbohydrate-high-fat or gluten-free diets over a long period of time, or a lack of food variety may increase the athlete’s need for nutritional supplements.

The increasing use of supplements

In many countries, the use of dietary supplements is a growing and lucrative industry, with more and more athletes using supplements due to their purported health or performance benefits. Unfortunately, these substances are not well regulated by governmental authorities. Many false claims are made regarding the potential effects of supplements, which are not supported by scientific evidence. Additionally, many supplements contain hidden ingredients, such as anabolic agents or stimulants, which may be dangerous to an athlete’s health. This is particularly the case for athletes who are engaging in high-intensity physical activity on a regular basis. These ingredients may also inadvertently result in a positive test during doping control. In general, it is advisable that all athletes, including athletes with impairment, avoid the use of supplements and instead strive to maintain a well-balanced diet that contains adequate caloric content.
content to meet their nutritional needs on a day-to-day basis.

**Conclusion**

Participation in sport and physical activity offers a myriad of benefits to individuals with impairment, ranging from community-based opportunities to elite sport experiences such as the Paralympic Games. Through this cutting-edge review of Paralympic sports medicine and science, all trainers, coaches, and team medical staff should feel comfortable working with this dynamic population, expanding inclusive opportunities and thus using sport as a catalyst for the enhancement of healthy lifestyles for all.

**References**


Chapter 5

The psychology of Paralympians and mental preparation

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Introduction

British sport psychologist Jonathan Katz once said, “The Paralympic environment is an intense, exciting, unremitting emotional roller coaster. It is also unforgiving and abrasive” (Katz, 2007, p. 28). He suggested that Paralympic athletes would be wise to prepare mentally for such an atmosphere. This chapter provides important information for athletes, coaches, and sport psychologists that will help Paralympic athletes to cope with, enjoy, and be successful in competition. The chapter is structured using a personal developmental model that revolves around foundation qualities, psychological methods and skills, and facilitative and debilitative factors (see Figure 5.1). First, research is presented on Paralympic (and elite-level) athletes falling within each section as follows: foundation qualities, psychological methods, psychological skills, facilitative factors, and debilitative factors. Next, research on elite-level athletes with intellectual impairment (II) is presented. The information on athletes with II is given separately because it is very limited and is quite eclectic. Finally, research on the role that coaches and sport psychologists play in Paralympic performance is discussed.

Coach’s Corner

“Enhancing self-concept is a vital goal in and of itself and... self-concept is an important mediating variable that causally influences a variety of desirable outcomes.”

(Marsh and Craven, 2006, p. 134)

The athlete

It is difficult for athletes to achieve excellence if they are deficient in various foundation qualities such as self-determination and healthy self-regard. Such foundation qualities may not directly influence performance, but they often have an indirect impact through training quality and lifestyle choices (Martin, 2012). Self-determination refers to people’s ability to feel in charge of their own lives. It is not uncommon for individuals with disabilities to experience feelings of powerlessness. In fact, success and failure experiences in disability sport are often seen as promoting feelings of empowerment and autonomy. Self-determination may also promote and lead to strong coping skills.

While self-judgments of worth are important, athletes with disabilities arguably face many challenges to developing and maintaining a healthy...
The psychology of Paralympians and mental preparation

Figure 5.1 Personal development model. Source: Martin 1999b. Reproduced with permission of Taylor & Francis.

self-concept. Many researchers have found that athletes often have to manage a plethora of negative feedback and a lack of affirming feedback both outside and inside of sport. Even well-intentioned feedback in the form of “supercrip” congratulations, which on the surface appear positive, can hide a patronizing focus on an athlete’s disability and a neglect of their athletic prowess.

Supercrip refers to the inaccurate perspective that individuals with disabilities are heroes simply by engaging in regular activities of common life, such as going to school or practice or going out to the supermarket. Supercrip also implies that accomplishing significant achievements (e.g., wheeling a marathon) is a sign of “overcoming” the disability. The problem with the supercrip stereotype is that most people with disabilities do not view themselves as heroes by simply living their lives and they do not usually view achievement as “overcoming” their disability. Coaches and other sport support personnel should reflect on their own beliefs and whether they have unconsciously endorsed beliefs consistent with a supercrip stereotype. Next, they should monitor their own feedback and praise to athletes to determine whether their language is reinforcing a supercrip stereotype. Such heightened awareness should help protect and insure that coaches are not inadvertently supporting a supercrip stereotype in their interactions with athletes.

“The unexamined life is not worth living,” a statement attributed to Socrates by Plato in the Apology (38a; Jowett, 2007), is familiar to many people and strongly suggests that self-awareness is critical to the human condition. A more contemporary definition of self-awareness is self-understanding of one’s thoughts (e.g., motivations) and feelings (e.g., anger versus frustration), and their influence on behavior (Martin, 1999a). Although athletes with and without disabilities are often very similar in their sport motivations, it is not uncommon for athletes with disabilities to have multifaceted and complex motivations. These motivations can range from typical sport goals (e.g., to perform well and win) to using sport in order to be seen as both normal and beyond normal. Adjusting to a recent disability, self-advocacy, fighting marginalization, and promoting the disability sport movement are all motivations that go beyond typical sport aspirations. Exploring and understanding such motivations may add meaning to an athlete’s sport experiences beyond the value found in achievement-grounded accomplishments. More than the more ethereal pronouncement contained in Socrates’ famous quote, there are some very practical sport self-awareness benefits.

Athletes with disabilities often deal with chronic pain and injury. Hence, self-awareness in distinguishing among disability-related discomfort, chronic pain from secondary conditions (e.g., shoulder tendonitis), a potential sport injury, and fatigue-related pain is important. An inability to sense the differences may lead to injury when attempting to train through pain or the loss of fitness by unnecessarily stopping training. Reducing time lost to injuries is critical, as many athletes with
disabilities have short careers and limited elite-level competitive opportunities.

The last foundation quality is personality. Personality is a relatively stable characteristic that is also thought to aid performance indirectly. The USA Paralympic gold medal (2004) women’s basketball team were more tough minded and less anxious compared to the elite women, who were the last athletes to be cut from the team at the national selection camp (Martin et al., 2011). The authors speculated that greater emotional stability (i.e., being less anxious) and resilience (i.e., being mentally tough) may have contributed to superior practice prior to the Paralympic Games and optimal performance during the selection camp. One last personality trait is sensation seeking. Preliminary evidence suggests that some athletes with disabilities are motivated to explore the outdoors (e.g., through skiing) because of the risk involved.

Little is known about the role of sensation seeking in Paralympians. However, sensation seeking has been implicated in dangerous driving behaviors, which in turn are often the cause of disability. It is possible that risky disability sports (e.g., snowboarding and skiing) may attract some athletes because of the danger involved. If this observation resonates with some athletes, they should consider whether they are prone to taking unnecessary risks inside and outside of sport. Cumulatively, foundation qualities can also be thought of as representing the core essence of an athlete and who they are. Many athletes with disabilities have strong athletic identities and identities grounded in being disabled. Identities are often reflected and assigned through the use of language. For example, the phrase “athlete with a disability” is thought to highlight the athlete, whereas “disabled athlete” is thought to highlight the disability.

There is a large amount of literature on the merits and shortcomings of the use of language associated with discussing disability in general (Dunn and Andrews, 2015). The literature in this area also addresses the use of language in adapted physical activity and sport specifically (Peers et al., 2014). Although arguments for the term adapted versus disability sport have been presented, the biggest debate seems to be whether the person or the disability should be first. Readers will note that I have used “athletes with a disability” to prioritize their athletic role, as that is the focus of the current chapter. However, it is important to note that not all writers or researchers working in this area would advocate the term “disability sport” or “athletes with disabilities.”

**Psychological methods**

This section offers recommendations for the use of common psychological methods to develop mental skills and qualities.

**Competition plans**

Athletes with disabilities often need to anticipate difficulties in order to plan ahead. For example, at the Athens Paralympic Games, a sport psychologist anticipated needing a farrier to help equestrian athletes. When a horse lost a shoe, such foresight was rewarded. Wheelchair athletes can access Hedrick and Morse’s (1995) wheelchair-specific precompetition and competition plans to help them focus and refocus during critical sport moments. All athletes benefit from examining their competition locations and becoming familiar with them. Familiarity helps athletes approximate the comfort of a home court or field and reduce the uncertainty that can cause anxiety. If physically accessing a location is difficult, even images (e.g., DVDs, pictures) can be helpful. Additionally, understanding the nuances of a competitive setting, such as how the puck bounces off the end boards of an ice rink, is important, in this case for Paralympic sledge hockey players.

**Coach’s Corner**

Have a competition plan and plan for the unexpected.

**Self-talk**

Positive and calming self-talk or energizing positive self-talk can help athletes with disabilities moderate their arousal up or down as required. Self-talk can also be used for maintaining correct
technique. For example, an archer might say to herself “Keep arm up” to prevent dropping the arm when fatigued. Goal-ball athletes have also effectively used instructional self-talk to their advantage. As a result of a psychological skills training program, Paralympic wheelchair basketball players have learned to become less self-critical. Negative self-talk surrounding past mistakes or negative future outcomes can divert athletes’ focus away from the present and “being in the moment.” The ability to recognize and reduce negative self-talk can have significant performance benefits.

**Coach's Corner**

Athletes should develop short, personalized, and meaningful self-talk sentences, such as “strong and smooth.”

**Goal setting**

Goal setting is a robust and well-supported self-regulation skill across diverse settings. Effective goal-setting principles such as realistic yet challenging goals and developing process (e.g., feel the arm extend), performance (e.g., wheeling a personal best time), and outcome goals (e.g., finishing in the top 20) are critical. Finding social support for goals (e.g., training partners) and the development of short-, medium-, and long-term goals are all goal-setting strategies with sound research support. Having a flexible hierarchy of goals is important to allow for the influence of uncontrollable events (e.g., illness). Athletes with disabilities should also set nutritional goals. Further recommendations can be set for goals that advance lifestyle practices commensurate with an athletic lifestyle (e.g., adequate sleep, limiting alcohol consumption). Competitive offensive and defensive goals (e.g., in wheelchair basketball and rugby) can be set to take advantage of opponents’ weaknesses and to minimize their strengths, and such goals will likely vary on a game-to-game basis.

**Coach's Corner**

Promote goals that range from dream goals to daily practice goals.

**Psychological skills**

Psychological skills are valuable for performance enhancement reasons and for motivational reasons that may minimize premature sport retirement. In a study of elite-level wheelchair rugby players, comprehensive mental skills predicted athletes’ sport engagement (Martin and Malone, 2013). Athletes with strong mental skills (e.g., the ability to concentrate or to cope with adversity) were more likely to report being dedicated and enthused about their sport compared to athletes with weaker mental skills.

**Efficacy and confidence**

Self-efficacy for both training and performance and for overcoming barriers to successful racing were positively linked to performance among wheelchair road racers (Martin, 2002). In a similar study (Martin, 2008), positive relationships were also found among training efficacy, performance self-efficacy, thought control self-efficacy, and resiliency self-efficacy for wheelchair basketball players. Both studies supported the generalizability of efficacy cognitions and relationships with affect. Finally, psychological skills, self-efficacy, and performance have all been positively associated in 15 elite amputee male soccer players participating in the Amputee World Cup.

**Coach's Corner**

Develop athletes’ efficacy by consistently reminding them of their practice successes.

**Coping, stress, and anxiety**

In a series of three related studies among British Paralympic wheelchair athletes, 10 major sources of stress were identified. Athletes were concerned about pre-competition issues (e.g., not making the team), poor competition preparation (e.g., malfunctioning equipment), on-court worries (e.g., limited playing time), post-competition stress (e.g., playing badly), negative aspects of a major event...
(e.g., being away from home), poor team dynamics (e.g., team disagreements), negative coaching behaviors (e.g., too much criticism), relationship issues (e.g., concern over partner being alone), demands of the sport (e.g., cost of equipment), and lack of disability awareness (e.g., inaccessible bathrooms and showers). Athletes dealt with unique sport stressors, disability-related stress, and common sport worries.

**Coach’s Corner**

Help athletes view stressors as challenges to becoming better athletes and people.

In the final study in this line of research, athletes cognitively appraised their stress levels. Athletes who perceived stressors as challenging also tended to view the same stressors as controllable. This finding affirmed the value of framing stressful events as challenges instead of unmanageable difficulties. Athletes who viewed stressors as severe were also likely to rate them as threatening and harmful. Negative coaching behaviors, relationship issues, and the costs of wheelchair basketball were the most severe stressors. Finally, the demands of wheelchair basketball were the most frequent stressors. Thus elite athletes with disabilities experience both sport-specific and disability-specific anxiety.

**Mood and emotion**

Mood states have commonly been researched in disability sport with a goal of determining whether athletes report an “iceberg profile” indicative of positive mental health. The iceberg profile is characterized by scores above the norm for vigor and below the norm for anger, confusion, depressed mood, fatigue, and tension.

**Coach’s Corner**

Promote optimal mood states by appropriate tapering and resting for major competitions.

Wheelchair athletes have reported lower anger, confusion, depression, and tension scores and higher vigor scores compared to wheelchair users who were inactive. Additionally, athletes exhibited iceberg profiles, indicative of mental health. Mood responses have also been assessed in the examination of an intervention program designed to teach athletes coping skills. Of the 24 athletes invited to try out for the USA Paralympic basketball team, all reported a positive mental health profile. However, the 9 athletes selected for the team reported less tension and anger compared to the 15 athletes who did not make the team.

Mood responses among elite athletes with cerebral palsy have also been examined. Athletes reported reduced tension and anger from the beginning to the end of the six-day camp, followed by an increase in tension and anger one month later at the Paralympic trials. Further, a comparison was made of 75 male visually impaired and 46 sighted beep baseball players competing in the World Series of beep baseball. Unsighted athletes were higher in depressed mood and tension. Visually impaired athletes may have experienced more tension because of limited time to adjust to an unfamiliar competition site. Since athletes with disabilities have typically reported iceberg mood profiles, this suggests that athletic participation might be associated with positive moods and a buffer against negative mood states.

**Facilitative and debilitative factors**

A host of non-sport-specific factors can influence how well athletes train, prepare for competition, and perform. For example, most athletes and coaches understand that sleeping and nutritional practices are important factors that influence performance. In this section a few important facilitative and debilitative factors that are unique to disability sport are discussed.

**Pain, injury, and illness**

Compared to able-bodied athletes, athletes with disabilities lose more training time due to injury. The International Paralympic Committee (IPC) has employed illness and injury surveillance
techniques at the Paralympic Games since 2002. During the Summer 2012 Paralympics, the injury rate was 17.8 injuries per 100 athletes, compared to the Olympic injury rate of 12.9 injuries per 100 athletes, suggesting a higher rate of injury for Paralympians.

Coach's Corner
Reduced training is always better than no training, so avoid turning minor injuries into major ones.

Research among athletes at the 1996 Paralympic Games also provided several interesting findings. Visually impaired runners experienced lower-leg overuse injuries that were similar in nature to their non-visually impaired counterparts, and athletes with unilateral amputations (i.e., one leg) suffered a high incidence of injury in the ankle area of the non-amputated foot/leg. For other athletes, the disability condition, sport-specific stressors, and use of any adaptive, assistive, or guidance aids (e.g., prosthetic devices), often interact, leading to the development of an injury. Shoulder injuries are the most frequent injuries among wheelchair athletes. It is likely that the everyday demands of wheeling combined with wheeling for training does not allow enough time for rest and adaptation to occur.

Athletes with disabilities may also be at risk of upper respiratory tract infections (URTI). For instance, wheelchair marathon racers experienced more URTIs (19%) than did the able-bodied participants (15.4%) in the two weeks after a race. Racers who continued to train hard after the marathon also experienced more URTI episodes compared to those racers training less, suggesting that they were overtraining. Finally, it is important to understand the increased risk of heat exhaustion and related outcomes (e.g., heat stroke) for athletes with spinal cord injuries, because they have difficulty regulating body temperature, particularly when competing in high temperatures.

Travel and lodging challenges
Traveling to competition sites for extended periods often means not being able to give or receive emotional support, which can cause stress and disrupt concentration. Travel-related issues may be viewed negatively and quite severely compared to other sources of stress. Traveling across timezones, dealing with foreign languages, and enduring different climates can all be stressful. At major competitions such as the Paralympic Games, athletes often cannot practice at the competition site, and are asked to room with individuals they do not know and who do not compete in their sport.

Coach's Corner
Do not schedule difficult and stressful practices immediately before or after long travel days.

Classification
In the current model of classification, athletes are often graded based on their capability to perform physical tests. As a result, athletes with different disabilities may compete against each other if they have the same classification. This classification system has been met with some controversy in the disability sport world and is undergoing rigorous scientific investigation and challenges. Regardless of the fairness of the system used, the classification procedure can be stressful. In particular, if athletes are reclassified at a different level, they could compete against athletes with a less severe level of impairment who can, presumably, perform better. The classification procedure is unique to disability sport and is a potential stressor.

Leaving sport
Paralympians often have very brief careers (e.g., two years) starting shortly after an acquired disability. Adjusting to a major trauma may take between two and four years. Hence, athletes may have to cope with continuing adjustment to their disability as well as with the transition out of sport. Additionally, they may have to deal with a “secondary disability” in the form of a chronic injury. A small body of literature exists in this area (Martin and Wheeler, 2011). In brief, worries about post-sport life may negatively affect athletes’ preparation for the Paralympics.
Coach's Corner

Call and email athletes after they retire to express care and interest in them.

Thus, while all athletes are affected by sport and non-sport life, Paralympians face unique challenges in the areas of pain, injury, illness, classification, travel, and retirement. These individual conditions and challenges may pose barriers to superior sport performance (Martin, 1999b).

**Athletes with intellectual impairments**

Sport psychology research on elite athletes with intellectual impairments (II) is rare, with just a few published reports. Additionally, this small body of research is not on Paralympians. Nonetheless, the findings should still be applicable to Paralympians. One of the first studies in this area reported that individuals with intellectual impairments were capable of learning relaxation skills. Gorely et al. (2002) reported on a psychological training skills (PST) program with 14 national-level Australian basketball players. Athletes were taught how to use cue words, employ positive self-talk, and relax. Interviews of athletes and anecdotal reports from coaches indicated that PST was perceived as valuable. The effectiveness of a PST program with three athletes who participated in Special Olympics track and field events has also been examined. The results suggested that athletes were able to learn goal setting, various types of self-talk, and imagery. Coaches are urged not to attempt to teach too many skills in too short a time period. In contrast, learning just a few mental skills very well is a preferred approach.

Research from related fields also has performance implications. For instance, in a study of over 300 high-performance athletes with intellectual impairments, researchers found that athletes with II had superior fitness in some areas (e.g., flexibility), but lacked fitness in other critical areas (e.g., endurance) compared to able-bodied athletes. Elite boccia athletes appear to experience muscular fatigue, resulting in impaired performance. This information suggests that when athletes, sport psychologists, and coaches develop training plans, they should focus on endurance training as well as skill enhancement, although such plans will certainly be contingent on athletes’ sport (e.g., boccia versus track).

Gorely et al. (2002) provide a number of useful suggestions to sport psychologists working with athletes with II. First, it is important to develop a realistic idea of the athlete’s capabilities and not to assume that they are limited by virtue of their intelligence. For instance, in one study swimmers with II were just as capable of streamlining their bodies as were elite non-disabled swimmers (Oh et al., 2013). Second, individuals with II often have quite varied communication capabilities, which makes finding the appropriate level of instruction challenging. Finally, while mental skill repetition is important, preventing boredom through variety and novel activities is also valuable.

Gregg (2010) has provided a number of suggestions for sport psychologists working with athletes with II. Because athletes with II may have trouble making autonomous decisions, it is important that sport psychologists allow athletes to make their own decisions. Gregg (2010) also advocates that specific and positive feedback is given frequently, along with developing routines to manage stressors. Finally, athletes’ understanding of mental skill development should be probed frequently through the use of open-ended questions. Simple yes or no questions should be avoided, as athletes with II might have tendencies to provide acquiescent types of responses.

The coach

Coaches are critical to success and can influence their athletes in a multitude of positive (and negative) ways. Disability sport in general tends to be
accorded secondary status relative to able-bodied sport. Although this is a speculative view, it is possible that some very accomplished coaches may not want to coach athletes with disabilities, as they might perceive such involvement as having less status compared to able-bodied sport coaching. Countries (e.g., Canada) with well-established institutional support for Olympic and Paralympic athletes often provide educational programs for their coaches. As a result, athletes from wealthy countries, like the USA and Canada, are much more likely to have ongoing high-quality coaching support. Canadian Paralympic swimmers, for instance, have continual access to the same high-level coaches as non-disabled swimmers. Paralympians from countries with limited financial resources may not have consistent coaching prior to competitions. As a result, coaches from such countries may act more as administrators during the Paralympics given their lack of prior involvement with their athletes.

Disability sport coaches have the dual challenge of understanding their athletes’ sport and their disability. In a study of four elite coaches of wheelchair rugby players in which the researchers examined their roles and responsibilities, two themes emerged: coaching the sport and coaching the individual. In regard to “coaching the sport,” coaches perceived that elite disability sport was in a period of transition and that creating an elite sporting environment was important. They believed that the most experienced athletes struggled with the increased expectations relative to the past, when making a Paralympic team was not as difficult as in the present. In the “coaching the individual” theme, coaches discussed the importance of changing the mindset of only practicing a few times a week with the team to regular, individual daily workouts outside of official practices.

Similar to the coaches interviewed in that research, elite swimming coaches have also affirmed the value of coaching swimmers as “elite swimmers” versus coaching a “swimmer with a disability.” Quality coaching provided by knowledgeable coaches is clearly an important influence on athletic success. In addition to the knowledge that a coach possesses, the interpersonal relationship between the coach and the athlete is also critical. For instance, in a study of eight swimmers with disabilities, a major finding was that all the athletes indicated that the positive outcomes they experienced in sport were linked to a very personal and close relationship with the coach.

In other research, disability sport athletes who viewed their coaches as supporting their autonomy expressed a strong sense of control over their sporting involvement and had positive relationships with their team mates. Also, athletes who viewed their coaches as supporting their desire to be independent had higher levels of intrinsic motivation relative to athletes who perceived their coaches as less supportive. The research on Canadian athletes has been supported by research with Jordanian national-level athletes. Athletes viewed their coaches as endorsing effective leadership behaviors (e.g., training and instruction, social support, positive feedback) from “occasionally” to “often.” Athletes were moderately satisfied with coaches’ training and instruction, and with the personal treatment that they received from the coaches.

Finally, athletes were more satisfied with their training, personal treatment, and team and individual performances if they also perceived their coaches as providing more social support, positive feedback, democratic behavior, and training and instruction. Additionally, autocratic leadership was only minimally related to athlete satisfaction, as athletes were less satisfied with how they were treated (i.e., personal treatment) if they viewed their coaches as employing more autocratic leadership behaviors. Autocratic behavior was unrelated to athlete satisfaction with training and instruction and with team and individual performance.

Cumulatively, the findings suggest that democratic behavior is positively linked to various forms of satisfaction, but autocratic behavior is only linked to one form of satisfaction. These findings highlight the value of coaches focusing on providing high-level instruction (e.g., specifying what is expected of athletes, correcting mistakes, explaining what to do, etc.). The coach’s influence on team cohesion is particularly important for sports where strategic and set plays are common (e.g., wheelchair rugby and basketball) and need to be learned in a short time span. Paralympic team athletes often
live in different parts of the country, making the development of team cohesion difficult. As a result, coaches’ influence on team task and social cohesion at national team camps is critical.

Disability sport coaches can also influence critical competitive psychological states in their athletes, in particular confidence and anxiety. For example, coaches who simultaneously support and challenge their athletes to become better are more likely to develop confident athletes. Elite athletes have viewed negative coaching behavior as one of the most anxiety-inducing sport stressors they have encountered. Effective coaching can clearly aid athletes’ performances, as demonstrated in one study. Using effective sport science techniques such as video and race analysis data, coaches were able to aid Australian athletes in developing effective race strategies (e.g., even pacing) that ultimately led to a 10% performance improvement, followed by a smaller improvement that ultimately resulted in a world record.

The Paralympic Games are the pinnacle of athletic competition. For elite Paralympic athletes, the Paralympic Games are about ability, competitiveness, effort, and winning. However, the path to success is contingent on superior training and preparation. As a result, to be as effective as possible, coaches must understand their athletes’ disability condition. Coaches striving to be the best coaches they can be should talk to their athletes about their experiences of living with a disability and how their disability influences their training and living an athletic lifestyle. This would suggest that experiences in the disability sport that one aspires to coach would be of value. Older sledge hockey athletes have stated that they thought their coaches would be more effective if they knew how to play sledge hockey. However, two coaches (of wheelchair basketball and wheelchair rugby) with disabilities, who coached athletes with disabilities, did not believe that it was critical to have had athletic experiences as athletes with disabilities. At the same time, researchers have found that coaches overwhelmingly viewed informal experiences (e.g., hands-on clinics, mentoring relationships, talking to athletes) as important components of a coaching education. For coaches of aspiring young Paralympians, developing sound relationships with the athlete’s parents and their physical therapists helps capture their individual athlete’s unique needs.

**Coach’s Corner**

“If you are coaching a swimmer with a disability it’s important to have good knowledge of what the disability is, that way you can make the distinction between what they can’t do because of the disability or because they choose not to. It can be a fine line figuring out how far you can push the athlete, but you have to understand the disability so you can make the right decisions.”

(Cregan et al., 2007, p. 346)

Coaches can also help athletes by considering the competition facility’s accessibility for their athletes. For instance, practice facilities can have doors too narrow for athletes to wheel their chairs through, causing some frustration. Coaches of Paralympians can also support their athletes with traveling issues. They can remind athletes that flying can promote dehydration and of the need to be well hydrated (i.e., insuring a supply of bottled water). Prior to traveling, and depending on the country, issues such as travel insurance, immunization, passports, and visas must also be considered.

Coaches can be influential even after they are no longer coaching, as illustrated by one athlete: “Nobody phoned, nobody asked me whether I would like to swim a little bit ... so I didn’t swim, maybe gained some weight ... nobody fought for me, including coaches and friends, I felt so small” (quoted in Hutzler and Bergman, 2011, p. 8). This suggests that individuals formulating institutional (i.e., the sport federation) policy and specific individuals in leadership roles (i.e., coaches) should consider whether they have a responsibility to help athletes transition out of sport by continuing to provide emotional support.

**Coach’s Corner**

Brainstorm with athletes about how they can remain in sport after they retire as athletes.

The classification process already described may be a setting in which athletes are tempted to cheat. Coaches need to be cognizant of athletes who may cheat (known as sandbagging) to get classified
The psychology of Paralympians and mental preparation

at a level lower than their capabilities, resulting in facing inferior competition. Of course, some coaches may support cheating as they, as well as athletes, strive to win. National federations may also be culpable, given that in 2000 the Spanish Paralympic Committee failed to test the Spanish II-basketball team to determine whether they were intellectually impaired. The use of performance-enhancing drugs is also present in disability sport and coaches should be able to deal with these ethical issues.

Finally, coaches can support the development of mental skills in their athletes. A survey of 10 Portuguese elite disability sport coaches found that two important themes emerged. First, all of the coaches believed that psychological preparation was important and that psychological skills were invaluable in helping athletes be psychologically prepared. Second, all the coaches believed that sport psychologists were important, but only one coach worked with a sport psychologist. Coaches viewed a lack of time and money, as well as athlete resistance, as barriers to having a sport psychologist involved.

The sport psychologist

Important information based on the involvement of Jonathan Katz (Katz, 2007) and other sport psychologists who have reported on their experiences at the Paralympics is summarized in this section. It should be noted that while sport psychologists may work predominantly with athletes for performance enhancement reasons, they may also provide services to coaches and other support staff (e.g., managers). An important preliminary step is to receive mentoring from other very experienced sport psychologists with prior experience at the Paralympic and Olympic Games. Katz was able to attend various training seminars (e.g., media training) developed by the British Paralympic Association, which aided his preparation.

One consideration common to two sport psychologists was helping out athletes through nonsport psychology functions. For example, one sport psychologist helped out with shopping for groceries, while another analyzed video. Although video analysis is not typically discussed as a sport psychologist competence area, the knowledge that he gained helped inform his sport psychology work. For example, team role clarification and individual feedback stemming from video analysis were used in consultations. The interactions with athletes during video analyses can also help establish rapport and credibility with those athletes. While these examples suggest relatively benign or positive outcomes of dual roles, it is suggested that Paralympic sport psychologists should be prepared to deal with role conflict and role ambiguity. As discussed next, role fatigue is also prominent.

A second common challenge involved managing fatigue while at the Paralympic Games. Often a lack of sleep accumulated over multi-day Paralympic events added to the experience of fatigue. A lack of on-site credentials resulted in extensive travel time (e.g., 60–90 minutes in one direction) between accommodation and competition venues. Limited day pass access (e.g., 9 a.m. to 9 p.m.) can also impose constraints on the services that a sport psychologist may be able to offer. Additionally, the distance between competition venues may restrict the services that can be provided. Thus sport psychologists, in a similar way to athletes, need to anticipate the challenges that they might face in attempting to “perform” and help athletes.

It is also important to note that at the 2004 Athens Paralympic Games, according to Katz, the two most common presenting issues were interpersonal issues (21%) and performance preparation (18%). The first issue indicates that sport psychologists should be prepared to help with factors that are ostensibly unrelated to performance, while recognizing that, in the words of US Olympic Committee sport psychologist Sean McCann (2008), “everything is a performance issue at the Olympic (Paralympic) Games.” Throughout his paper and as noted elsewhere, Katz (2007, 2009) appeared to benefit greatly from engaging in daily reflective practice, documented in a daily diary.

Finally, it should be noted that for ongoing sport psychologist–athlete relationships, much of the work in mentally preparing for the Paralympic Games will be done much earlier. Katz, for instance, worked with athletes in Cyprus at a pre-Paralympic camp prior to traveling to Athens. In another
report, Larson (2013) describes his work over a six-month period helping the Danish national goalball team prepare for the European Championships, which they won. Larson (2013) provides a thorough description of his work with the players on developing communication and cohesion and the manner in which he and the team and coaches worked together.

Conclusion

A sense of self-determination, a healthy self-concept, enhanced self-awareness, and emotional stability are seen as important for mental health and indirectly influence performance. These positive psychology concepts and personality factors are also important for athletic success. For example, it is hard to envision athletes being able to train and compete at an optimal level for many years in order to make the Paralympic Games if they feel powerless, do not value who they are, lack insight into themselves, and are neurotic. Such an athlete would be prone to anxiety, stress, and depression, and at risk of becoming demotivated.

Athletes should use psychological methods to achieve mental skills and qualities. Learning how to self-regulate through goal setting and positive self-talk to enhance and maintain motivation and efficacy is an example of the psychological method–skill link. Athletes do not live in a vacuum and their disability, sporting, personal, and professional lives all influence their sport experiences and successes. Finally, sport psychologists and coaches play important roles in helping Paralympians pursue their goals. Using sport psychology concepts for their own benefit can increase the quality of support that coaches and sport psychologists are able to offer.

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Introduction

The intent of this chapter is to highlight to sport coaches the value of thinking sociologically when it comes to gaining an understanding of Paralympians and how training may vary from mainstream sporting contexts. The science of sociology can be a good window through which to understand the social role that disability can have in shaping the training and coaching contexts of individuals who come along to sports clubs (including those that typically do not offer programs to people with disabilities). Of course, not everybody with a disability will have the ability to become a Paralympian, because there is a high degree of physical competence required, but the principal intent behind this chapter is to illuminate to coaches that with attention to the social world in a sociological manner, their own interventions may be enhanced.

Coach’s Corner

“Every aspect of the ‘coaching act’, from the conditioning and athlete development, to performance analysis and theories of training is somehow influenced by the social construction of knowledge ... However, when it comes to educating coaches, concern over the social nature of coaching are often overlooked.”

(Denison, 2007, p. v)

In recent years the development of the academic field of sport coaching has highlighted the significance of enriching social scientific understanding of the coaching environment (Denison, 2007). While the sociological literature to date has not in any systematic fashion focused on Paralympic coaching, in the past there have been coaching manuals that have been developed to highlight the requirements of coaching athletes with disabilities (Goodman, 1995). This type of coaching manual can be of use in setting the stage for inclusion. They provide the foundation to help transform the culture of physical education and sports (Nash and Collins, 2006) that will enable coaches to guide potential Paralympic athletes successfully. By engaging a sociological imagination (Wright-Mill, 1959), coaches and athletes can better understand the social context surrounding the coaching process.

To achieve this aim, this chapter outlines key elements of debates in the field of the sociology of sport, giving coaches insight as to how thinking sociologically can be useful in avoiding social barriers to participation of young people with disabilities. In this way a good coach can be instrumental in helping a young athlete become a Paralympian.
Coach’s Corner

Leadership is very important in the coaching context, but the draconian methods of the past are today increasingly frowned upon. Good coaches work in harmony with their athletes as a collective that endeavors to achieve their “on-field” goals. Just as important is the process of attaining these goals. The process allows both the coach and the athlete to discover themselves more completely, giving them the opportunity to contribute positively to the broader society.

Debate and discussion surrounding the social scientific exploration of the Paralympic Games and coaching centers around two key sociological concepts, structure and agency. The first of these two concepts refers to the social structure of society and refers to features of social organizations or mechanisms including institutions, roles, and statuses, which are believed to ensure the continuity of patterns of behavior and group relationships over time. Agency, on the other hand, highlights the ability of individuals to effect social change, make independent and autonomous choices, and act in self-determined ways. Therefore, structure is seen as static, rigid, and unchanging, whereas agency is flexible and the degree to which it is applied is ever-changing. Social scientists such as Pierre Bourdieu (1977) and Anthony Giddens (1979) and their numerous followers have used the relationship between structure and agency in the past to good effect when exploring the social world.

A fair amount of high-quality social scientific research into Paralympic sport balances the role of the structure of society against the desire of individuals to transform the Paralympic movement. In other words, small changes instituted by the leadership within the Paralympic family have the possibility of altering the direction of the movement, but often not to the extent that one might imagine, since the structure of the organization has a stabilizing quality that means that the pace of social change may be slower than desired. In this chapter, a number of issues are emphasized that contemporary social scientific research into the Paralympic Movement considers of importance, in the hope of encouraging more scholarship in this fascinating field of study. At the structural level, the chapter focuses on the issue of integration of athletes with disabilities into “mainstream” sports and the sociological interpretation of athlete classification. Paralympic bodies (organizations) are the focus of the second part of the chapter, because it is at the level of the individual with an impairment where issues of agency can best be explored. Specifically, issues related to severe disability, gender, and technology are highlighted. Before discussing these issues, however, the chapter begins by considering the relevance of disability studies to Paralympic research.

Paralympic research and the field of disability studies

It is only in the last decade that social scientists of sport who have chosen disability as the focal point of their research have actively embraced the existing literature in the field of disability studies. This body of work, which is a direct product of a political movement led by people with disabilities themselves, has given researchers whose focus is the Paralympic Games an ability to explore more deeply the importance of the disability sport movement. Early work on Paralympians was little more than a description of various adapted physical activity practices that became part of the Paralympic Games. Over the last 15 years, social scientific research on the Paralympic Movement has been transformed in large part by the adoption of more critical conventions used in the field of disability studies, which owes part of its roots to sociology. For example, it has been widely accepted within disability studies circles that a “person first” approach should be adopted when addressing persons with a disability. That is to say, it is more appropriate to refer to “athletes with disabilities” than to “disabled athletes.” Some of the quotes from the work of scholars in the field used to highlight points in this chapter adopt the latter term, disabled athlete. These should be seen as part of the social historical record of changing attitudes toward disability.

Within the field of disability studies, the choice of words employed to discuss individual athletes who engage in Paralympic sport is also seen to have political relevance. When the phrase “sport for the
disabled” is used instead of “disability sport,” it becomes clear that sporting provision for the disabled is part of what might be labelled a “disability industry.” Therefore, because Paralympic sport is run largely by the “able,” the phrase “sport for the disabled” seems appropriate. While some people who are familiar with this field of study may see the phrase “sport for the disabled” as outdated in properly exploring the Paralympic movement in social scientific terms, it is vital that coaches are reminded of the social hierarchy that is at play in all cultural contexts.

Disabled activists and theorists make the distinction between impairment, an acquired or born trait, and disability, the wider impact of the social context of these impairments; the sociological literature on Paralympic sport has increasingly adopted this approach. The view that disability is a social construction is known in the field of disability studies as the “social model” of disability. This model is seen as being in direct opposition to the “medical model,” which highlights disability as a medical problem. To those who advocate the social model, impairment is a functional trait, or in lay terms what is “wrong with a person,” which often has consequences as to whether the person’s body is seen as “normal.” It has been suggested that “impairment” does not necessarily create dependency and a poor quality of life; rather, it is a lack of control over the physical help needed that takes away people’s independence (Morris, 1996, p. 10). By extension, it appears that “sport for the impaired” might be a more appropriate term than “sport for the disabled,” yet the former lacks the overt political connotation that is culturally relevant within sociological approaches to Paralympic sport.

Coach’s Corner

It is important that coaches are aware of the political winds surrounding Paralympic sport, because in many cases they can influence whether or not an athlete will have the desire to compete on the Paralympic stage.

One area where a sociological understanding is helpful is related to the medical taxonomy that is at the heart of Paralympic classification. Medical taxonomic categories were the foundation for the classification system established by the International Organisations of Sport for the Disabled (IOSDs), which remain an integral part of the Paralympic Movement along with the Cerebral Palsy International Sport and Recreation Association (CP-ISRA), International Blind Sport Association (IBSA), International Federation for Para-athletes with an Intellectual Disability (INAS), and the International Wheelchair and Amputee Sport Federation (IWAS). The IOSDs developed their own classification systems to facilitate what they felt was equitable participation between their athletes. These classification systems are no longer seen as appropriate by the International Paralympic Committee (IPC), but the IOSDs set the initial standard from which all future systems would be judged.

The development of Paralympic sport through the IOSDs, which have a charitable mandate, has had a negative impact on certain impairment groups. It was the IOSDs and their predecessors that helped to organize the Paralympic Games from 1960 through to 1988 (see Chapter 1). The fact that these Games were staged at all is a testament to the commitment of those involved with the IOSDs. For example, athletes had to raise substantial sums of money for the opportunity to compete in the Paralympic Games in 1988. Those who could not raise the funds were replaced by athletes who might have been less proficient in their chosen sports, but were better fundraisers. Athletes as well as officials went cap in hand to other charitable organizations in order to fund their involvement in the Games (Brittain, 2010).

As a result, early Paralympic Games placed less emphasis on high performance and more on the opportunity for international participation. This is not to say that elite athletes were not involved, but that participation was the main imperative. This ethos of participation has been difficult for many of the IOSDs to move away from and hence has added tension to their negotiations regarding athlete classification and IPC programs. As a result, there has been a reluctance to devolve power to the IPC for fear that their athletes will lose the opportunity to participate in the Paralympic Games and IPC World Championships (Brittain, 2010). The
charitable ethos of the IOSDs led the Paralympic Movement to celebrate participation over performance, and as such is still a central component of Paralympic culture.

**Coach’s Corner**

It is important that coaches of potential Paralympians are keenly aware that there still exists a tension between those who see the aim of the Paralympics as being about participation and those who see it simply as high-performance sport.

For the vast majority of National Paralympic Committees (NPC), only the very best, highly trained athletes are selected to compete for their nation. The Paralympic Games today is a high-performance spectacle and should be celebrated as such, but from a sociological perspective it is important to remember how and why the Games were organized in the past. This chapter will now turn to the sociological interpretation of integration in sport, before considering the classification of Paralympic athletes.

**Integration and sport for the disabled**

The integration of athletes with a disability that is being undertaken by mainstream sporting organizations in many western nations is seen as important if an inclusive society is to be achieved. Integration, broadly speaking, is the equal access and acceptance of all in the community. Coaches who work in an environment where encouragement in training or teaching contexts exists are practicing integration. Some scholars have distanced themselves from discussion of integration, on the grounds that the concept implies that those in the disabled population are required to change or be normalized in order to join the mainstream (Ravaud and Stiker, 2001). In other words, the concept of integration requires members of the disabled community to adopt an “able” disposition in order to become members of the mainstream. However, other scholars working within the social scientific investigation of Paralympic sport have adopted a concept of integration that is useful in the current overview of this field. Sørensen and Kahrs (2006), in their study of integration of sport for the disabled within the Norwegian sport system, have developed a “continuum of compliance” that aims to explore the success of their nation’s inclusive sport system. Within this study, “integration,” where both athletes with disabilities and those from the mainstream adapt their cultural systems, is referred to as true integration. An athlete with a disability who is forced to adopt the mainstream culture without any attempt at a reciprocal action is undergoing assimilation. On the continuum, the least integrated model is seen as segregation, where neither group is willing to transform its core cultural values in spite of being jointly managed within the sport system.

Those working and researching in Paralympic sport would be most content if integration was true in the sense discussed here and one assumes that a coach reading this chapter would as well. If sport, and by extension society, is going to become more inclusive, “it is necessary for existing economic, social and political institutions to be challenged and modified. This means that disabled people are not simply brought into society as it currently exists but rather that society is, in some ways, required to change” (Northway, 1997, p. 165). In the long term, this might ultimately mean that the IPC and the International Olympic Committee (IOC) become equal partners, as this would be an overt indication that true integration had taken place.

This conceptualization of integration reflects recent work arguing that integration can be effectively understood as an outcome of an inclusive society. More specifically, it is argued that “integration occurs through a process of interaction between a person with a disability and others in society” (van de Ven et al., 2005, p. 319). In other words, it is the process of interaction between an individual with a disability who possesses their own attitude toward integration, strategies, and social roles, and others in society who adopt certain attitudes and images of people with disabilities. As a result, factors that influence the success of the integration process are both personal as well as social, but also include an element of support provision that will be distinct depending on the severity of the individual’s disability. A key point here is that
the vast majority of coaches who work with potential Paralympians will be able-bodied and this may reflect on society’s prejudice against people with a disability.

**Coach’s Corner**

Using a sociological lens, all coaches must reflect on why they are coaching Paralympic athletes. If you are doing it to enhance an athlete’s sporting performance this is appropriate, but if you are coaching for your own self-serving ends then I would urge you to reconsider your involvement.

It is possible to see true integration as a literal intermixing that entails the culture of both groups adapting to a new cultural environment. Dijkers (1999) uses the term “community integration” to articulate a similar concept to true integration. Community integration, according to Dijkers (1999, p. 41), “is the acquiring of age, gender, and culture-appropriate roles, statuses and activities, including in(ter)dependence in decision making, and productive behaviours performed as part of multivariate relationships with family, friends, and others in natural community settings.” True integration, therefore, is “a multifaceted and difficult process, which although it could be defined at a policy level rhetoric, [is] much less easy to define in reality” (Cole, 2005, p. 341).

The difficulty when exploring the success of integration policies is that the balance between the philosophical position and the reality (in this case a sporting context) is not always clear. Simply exploring the policy landscape means that any interpretation of the sporting context is devoid of explicit cultural influences, although all policy is a cultural artefact. This being said, the ultimate aim of integration should be to allow people with disabilities to take a full and active role within society, and this includes the roles of coach and trainer. The ideal would be a “world in which all human beings, regardless of impairment, age, gender, social class or minority ethnic status, can co-exist as equal members of the community, secure in the knowledge that their needs will be met and that their views will be recognised, respected and valued. It will be a very different world from the one in which we now live” (Oliver and Barnes, 1998, p. 102).

Within the context of high-performance sport, this aim is hard to achieve. By its very nature elite sport is selective, as Bowen (2002, p. 71) suggests: “Within professional sport, though, all but the super-able ‘suffer’ from ‘exclusion or segregation’” and “sport isolates individuals, but only those who are super-able. The rest are left to the realm of the minor leagues, master’s leagues, local tournaments, or backyard pick-up games.” International sporting organizations should achieve true integration at the high-performance end of the spectrum in order to send a clear message regarding the positioning of people with disabilities within wider society.

**Disability sport and classification**

Categorizing the body of athletes with a disability based on the degree of functional difference places it on a continuum where one trait may make an individual less marginalized than someone else who exhibits another, different trait. While categorization is often seen as not being problematic within the Paralympic Movement, it has had a negative impact on the wider disabled community, by placing various impairment groups in a hierarchy of acceptability where some impairment is more marginal than others. The notion of the categorization of impairments that leads directly to a marginal position in society stems from the work of Erving Goffman (1963). *Stigma: Notes on the Management of Spoiled Identity* was one of the first studies that drew attention to the nature of the problem of stigmatization for people with impairments. Some critics of disability research have argued that the role of studies of stigma was an attempt to medicalize disability in order to classify it with respect to the predominant views expressed by society at large. For this reason, Goffman’s work on stigma is useful when exploring the categorization or rather classification of athletes with a disability within Paralympic sports.

A coach of a potential Paralympian needs to be aware that a complex athlete classification system is in place at all IPC events. Coaches will need to have the athlete classified to determine with whom they will compete. This is not a difficult process,
but it is needed to make the outcome of sporting competitions as fair as possible.

With regard to the history of classification, the IOSDs were on the front line offering expertise when the IPC was established in 1989. Many of the first officials of the IPC had previously held posts within these founding organizations. Consequently, there was initially carte blanche acceptance of the IOSDs’ classification systems in the early days of the Paralympic Movement. The sport of track and field athletics still uses a largely disability-specific classification system, whereas swimming used a functional integrated classification system, developed to enhance the potential for integration (Steadward, 1996). The use of the functional integrated classification system reduced the number of classes for a group of athletes by focusing on functional ability rather than disability, and ultimately led to an increase in the number of viable events at major championships. This system is no longer acceptable within the IPC, where evidence-based classification is favored, but the use of integrated functional approaches can be seen as a step toward the development of ever more rigorous practices in classifying athletes with disabilities for sport.

Classification in Paralympic sport is simply a structure for competition similar to the systems used in the sport of judo and boxing, where competitors perform in distinctive weight categories, except for the fact that athletes are able to diet themselves out or eat themselves in to such categories. Within Paralympic sport, athletes will be classified in an attempt to minimize the impact of their impairment on the outcome of competition. Therefore, it is important that the classification process is robust and achieves equity across Paralympic sporting practice, enabling athletes to compete on a “level playing field.” As Sherrill (1999, p. 210) suggests, “one of the basic goal[s] of classification is to ensure that winning or losing an event depends on talent, training, skill, fitness, and motivation rather than unevenness among competitors.”

The practice of classifying for sport has been largely a medical one, and can lead to stigmatization and alienation because it ultimately creates a hierarchy of bodies. This hierarchy is of the impact of impairment on activity limitations or on competitive outcome. Such hierarchies may have a negative impact on the identities of people with disabilities involved in sport and throughout life more generally (Deal, 2007).

Coach’s Corner

The culture that surrounds the practice of Paralympic sport and the knowledge that participants and their coaches have of their bodies and their self-identity mean that working toward achieving goals on an individual level is just as important as the work done through and by institutions such as the IPC. Through work on and with the body, athletes’ experience, establish, and extend their limits and abilities, while placing them in the context of a number of rules and styles that make up social circumstances. This is not simply a matter of doing exercises, but of monitoring and refining, keeping training records and making confessions, giving and taking up different behaviors. Such rigorous planning has been part of high-performance coaching for over a century.

While athletes’ participation in Paralympic sport may be seen to be controlled through classification, it is important to note a number of key factors when establishing a complete sociological picture. First of all, the process of classification “belongs” to the sport. Only a few sports are still under the umbrella of the IPC, hence the IPC cannot control all systems in place. Secondly, many sports, such as swimming, are not necessarily disability based. The IPC also has recently developed a classification code to make the classification process as consistent as possible. It suggests: “The classification code will aim to synchronise all sport specific classification processes and procedures, in much the same way that the world Anti-Doping Code has done for international anti-doping rules and regulations” (International Paralympic Committee, 2004, p. 11). In this manner, the classification code has acted as a catalyst for various sports to make their classification systems more robust. Perhaps most significantly, the IPC recently accepted a Position Stand on evidence-based classification (Tweedy and Vandewiel, 2011); that is, a system whereby the purpose is stated unambiguously and empirical evidence indicates that the methods used for assigning class will achieve the stated purpose. Importantly, this position is not disability based.

In this regard, the world of contemporary Paralympic sport is indistinguishable from the sporting
mainstream except for the impact of the process of classification. This is in part why classification may be seen as central to a sociological investigation of Paralympic sport. In essence, the classification an athlete receives may go some way in determining whether or not he or she is considered elite, regardless of the quality of the training used. While other sporting practices have forms of classification, such as age and weight, because the general population varies across these categories they are less restrictive than the protocols established within Paralympic sport.

Classification within Paralympic sport has been one of the long-standing disagreements between the IOSDs and the IPC, since the latter feels that the integrated functional classification system advantages some impairment groups over others and is not evidence based. Critics of this system suggest that some impairment groups may be at a systematic disadvantage and in some cases may no longer be able to compete. Specifically, the system may be more difficult to classify because of the need to consider a great number of impairments simultaneously, and many of the tests used have not been statistically validated. Fifteen years ago, there was even fear that athletes would “cheat” the system by fooling the classifiers because the classification tests have not been validated. According to Wu and Williams (1999, p. 262), this has been a problem within the sport of swimming:

Misclassification is an interesting and perennial problem in disability sport. As with many others, it is the root cause of much frustration and anger (a) among swimmers who feel they have been disadvantaged by losing to a competitor who should be in a higher class and (b) among coaches and swimmers who may believe that they have been disadvantaged by being placed in a higher class than their impairment warrants.

Perhaps more importantly, athletes may be penalized for enhancing their own performances, since training as an elite athlete is central to the culture and identity of the majority of Paralympians. If athletes train and improve their technique in swimming (or any sport that adopts an integrated functional classification system), they may be reclassified based on their new ability. This is a key concern, as Vanlandewijck and Chappel (1996, p. 73) have pointed out:

The concept of athletic excellence can only be fully appreciated when the performance is related to the functional physical resources available to the athlete in competition. These resources represent the athlete’s performance potential. Whether such a potential is fully utilized by the athlete is one crucial determinant of excellence. An acceptable classification system would allow the definition and measurement of performance potential. The definition of potential in this way is the cornerstone of the classification process.

This quotation highlights some of the sociological conundrums in the investigation of athlete classification. International Classification of Functioning, Disability and Health (ICF) terminology was not used at the time of publication of this statement and therefore the concept of functional potential is not defined in these terms. In the current era with a classification code, an evidence-based approach, and ICF terminology, one can but hope that the problems highlighted in swimming will be eliminated and not simply replaced by other matters. Of course, one of the ways in which this is chronicled is to engage in a further social scientific diachronic study. In practice, the determination of sporting potential is almost impossible to achieve through any classification system. Yet the aim of achieving as fair a competition as possible is still the goal of the classification process, and the place that one’s body occupies within a category may have a significant impact on one’s identity.

**Coach’s Corner**

Classification is the mechanism that allows for the practice of Paralympic Sport on a “level playing field.” The athletes with whom you work as a coach will be assessed by qualified classifiers in order to establish their eligibility to compete. Some athletes with disabilities are not eligible to compete in the Paralympic Games, but that does not mean that they cannot benefit from being actively involved in sport at the participation level. If a new athlete attends your training sessions and has a desire to compete in Paralympic sport, you should contact your National Paralympic Committee in the first instance to see when the next opportunity for classification will be in your area.
Processes of classification within Paralympic sport for athletes with a disability make distinctions between physical potential and attempts to achieve an equitable environment, enabling successful athletes in each class to have an equal chance of accumulating physical capital – that is, reward for sporting excellence. In reality, however, there are a number of factors that affect the accumulation of capital (both physical and cultural) in various classifications. The first is the number of athletes within a particular event. If there are only a handful of athletes in an event, then the amount of capital that can be accumulated in most cases is limited. In some classes there may only be six athletes from four countries (the IPC minimum for eligible events), which means that winners are less likely to receive the same kudos as an athlete who defeats 20 others. Another important factor in terms of whether winners ultimately gain capital from their involvement in sport is the nature and degree of their impairment. A component of the culture of Paralympic sport illuminates a hierarchy of “acceptable” impairment within the community of athletes, where the most “able” are seen as superior to the more severely impaired (Sherrill and Williams, 1996).

**Paralympic bodies**

The first half of this chapter has addressed some of the institutional structures within Paralympic sport, most notably classification, and should give coaches an understanding of the socio-political landscape they are in or will soon be entering. Because the Paralympic Movement is relatively young, the changes and transformations that are ongoing within the classification system are a normal state of affairs; the aim, after all, is to provide fair competition. It is hoped that the evidence-based approach to classification will be an improvement on previous systems. Coaches and athletes must remember, however, that any system will have consequences (both positive and negative) for Paralympic athletes. The second half of this chapter will explore issues related to agency by using the bodies of Paralympians as a vehicle to explore how individual athletes may be affected by the social world surrounding contemporary Paralympic sport.

The bodies of impaired athletes have continually been judged in relation to an able-bodied “norm” and the standards of play and performance are compared with those of mainstream competitions. This can have an adverse effect on participation rates within Paralympic sport, as these bodies do not often match up to the able-bodied norm:

> It is through the study of the body in the context of, and in relation to, sport that we can understand sport as one of the sites for the reproduction of social inequality in its promotion of the traditional view of athletic performance, masculinity, and physicality, including gendered images of the ideal physique and body beautiful.

(DePauw, 1997, p. 420)

Sport is an embodied practice and, as such, many people who possess less than “normal” bodies may withdraw from the masculine physicality often associated with sport. In sociological terms, bodies can be seen to take center stage in many lives, for athletes and non-athletes alike. Following Seymour (1998, p. 4), “embodiment is our life-long obsession. Eating, sleeping, washing, grooming, stimulating and entertaining our bodies dominate our lives.” For athletes with a disability, the manner in which they are embodied often marks them out for “special” treatment in society, as their bodies highlight these individuals in a meaningful way as imperfect and therefore inadequate. This is because a lack of a physical impairment is seen as normal. The imperfect body highlights the opposite – a lack of normality. A coach who works in a “special” school environment is likely to have a distinctive take (not necessarily a better one) on Paralympic sport, but exposure to how sporting publics treat bodily difference may influence whether athletes continue in their chosen sport.

**Coach’s Corner**

Today in many cases congenitally impaired individuals are schooled in inclusive environments, but depending on the nature of the impairment they may or may not engage in a segregated physical education environment. Regardless of the type of access they have to organized sport, the socialization of these young people will be distinct from those who attend “special” schools.
In the context of Paralympic sport, there are two broad types of bodies that are of concern: those with either congenitally or acquired impairments. Both broad types of bodies will have traveled different roads before they got involved in Paralympic sport. Individuals with congenital impairments traditionally would have attended “special” schools. Early congenitally impaired Paralympians would have perhaps gained their first exposure to sport through adapted physical activity classes at their school. These early experiences will have been instrumental in shaping their sporting experiences.

Those who come to Paralympic sport as a result of a traumatic accident, such as a car crash, are often socialized differently than congenitally impaired individuals. If the traumatic injury occurred in their youth, these individuals may also have attended a “special” school or had adapted physical activity classes as their introduction to sport. If the traumatic injury happened after the age when young people attend school, there is bound to be a period of transition to the new bodily circumstances. These individuals, regardless of age, go through a process of rehabilitation where their bodies need to be retrained, often in the most basic tasks such as the management of daily hygiene regimes. After these individuals have relearned basic tasks, or perhaps alongside these activities, they in essence become re-embodied; that is, they learn some of what their “new” body can and cannot do in an adaptive physical activity setting where sport can be a feature of their lives.

Both congenitally and acquired impaired bodies that make up the major subgroupings within the Paralympic Games can be further subdivided into athletes with a severe disability or those without a severe disability. In 2005, the IPC Athletes with High Support Needs Committee (AHSNC) produced a revised definition that includes a specific list of sport classes where persons with a severe disability compete. The current definition is: “An athlete who requires assistance during competition, based on the rules of the sport and/or an athlete who requires support staff in the sport environment, including for daily living functions, travel/transportation, transfers, etc.” (International Paralympic Committee, 2005, p. 10). The AHSNC was established to increase involvement of the most severely impaired athletes in the Paralympic Movement. For these athletes, the sports in which they compete have to be the most adapted and their physical prowess is the least acknowledged within the Paralympic Movement. This should not be a surprise, because even Paralympic sport is ultimately about physicality. In an environment where the body is essential such as sport, imperfection becomes evident. DePauw (1997, p. 423) examined how sport marginalizes the disabled and argues the need to re-examine the relationship between sport and the body as it relates to disability:

Ability is at the centre of sport and physical activity. Ability, as currently socially constructed, means “able” and implies a finely tuned “able” body. On the other hand, disability, also a social construction, is often viewed in relation to ability and is, then, most often defined as “less than” ability, as not able. To be able to “see” individuals with disabilities as athletes (regardless of the impairment) requires us to redefine athleticism and our view of the body, especially the sporting body.

This is a laudable goal. However, to redefine athleticism would require an overhaul of sport itself. The point that DePauw makes is an important one in relation to the AHSNC, and this is only one of the key issues for this IPC group: to ensure that these athletes are celebrated for their physical prowess.

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**Coach’s Corner**

As a coach of a high-performance athlete, your concern should not be whether your athlete’s performances are celebrated, but rather that you do everything you can so that the athlete’s goals are achieved.

It is not just AHSNC athletes who are marginalized through the practice of sport, because, as DePauw (1997) suggests, masculinity, physicality, and sexuality are integral aspects of sport and each of these is a social construction. Therefore, these three components have socially ascribed definitions and together these elements marginalize bodies that do not fit into society’s definition of sport. Athletes who are the concern of AHSNC have
traditionally been marginal to the practice of sport. According to the IPC website:

At their meeting in June 2014 the IPC Governing Board considered that a greater emphasis was needed on the work of the Athletes with High Support Needs Committee through the creation of a Working Group. The Working Group will explore the possibilities for developing a revised function and creating the best structure for a committee that can drive all aspects forward to better represent athletes with high support needs within the IPC governance structure.

Women have also traditionally been marginalized in the context of sport and therefore it is not surprising that the IPC has a committee to give voice to female Paralympians. Paralympic female athletes are not unlike their able-bodied peers, who have also been marginalized in the context of sport (DePauw, 1997). In the Paralympic Games in particular, low numbers of women competing in events are seen by some as a result of the double bind that women with disabilities must face. According to the IPC website (http://www.paralympic.org/the-Ipc/committees/women-in-sport), the Women in Sport Committee was established for these reasons:

To advocate and advise on the strategies and policies to obtain the full inclusion of women and girls at all levels of Paralympic sport and the Paralympic Movement and identify barriers that restrict participation, recommend policies and initiatives to increase participation. The Women in Sport Committee was formed in response to the repeated concerns of the IPC Membership regarding the low participation of women within the Paralympic Movement.

As Seymour (1998, p. 119) suggests, because of the connotations with masculinity it is a strong male body that resonates with the re-embodied image of a high-performance athlete:

A winning wheelchair athlete is seen as the epitome of rehabilitative success. The vision of the strong male bodies competing for honours on the sports field is an image that has currency in the able-bodied world. Bravery in overcoming the catastrophe of a damaged body is a quality everyone can admire.

Of course, not everyone can match up to this image. Even a male who has used a wheelchair all his life does not have a heroic tale to go with his achievement in the same way as someone impaired in an accident might. Those with more severe impairments may never be able to achieve the image of the successful wheelchair hero. Therefore, the image can be counterproductive to the equitable treatment of people with disabilities, as not everyone can achieve this form of re-embodiment. The use of role models with a particular physicality due to spinal cord injury “may disenfranchise the very people who most need its services. The creation of sporting heroes as rehabilitative triumphs obliterates from view the many severely damaged people for whom such activities will always be an impossibility” (Seymour, 1998, p. 120). In other words, social issues like gender and degree of impairment are subjects of concern that in a more detailed sociological account should not be treated in isolation.

The masculinity that makes the highly functioning male wheelchair body cause for celebration will lead some women with the same physique to be seen as lacking femininity. The pressure for those with severe impairments to conform to able-bodied norms is great, but it also has a gendered component. A physical or intellectual impairment can be seen as a threat to masculinity. Some gender scholars have suggested that control over senses and physical and mental toughness are attributes that have traditionally led to hegemonic masculinity (Connell, 1995). Hegemonic masculinity implies that more often than not men are in positions of control within society, which is a reflection of their strong masculine identity. The presence of an impairment undermines this social order. According to Connell (1995, p. 54), “the constitution of masculinity through bodily performance means that gender is vulnerable when the performance cannot be sustained – for instance as a result of physical disability.”

Coach’s Corner

The low participation of women within Paralympic sports is in part due to women being influenced by the dominant gender ideology. Some women may perform at a high level in sport, but many with disabilities choose to avoid sport because of its close association with masculinity and the non-athletic images of desired femininity.
Since sport embodies hegemonic masculinity, it has been popular with men with disabilities as a vehicle for reclaiming and re-embodying themselves. Like men, women can regain body function through rehabilitation regimes that may have sport as a constituent part, but “such activities do not have the same powerful effect for women as they do for men since such bodily attributes are associated with masculinity and are considered to be contradictory aspects of femininity” (Seymour, 1989, p. 114). The centrality of the perfect female body in western societies has sparked an increase in physical activity and fitness regimes, particularly among young able-bodied women. When these activities are commodified, a great majority of women with disabilities are discouraged from becoming involved as a result of the understanding of how a healthy female body should look. Nevertheless, some women with disabilities do reshape their bodies through exercise regimes generally and participation in sport more specifically.

It must be remembered that these women fall into the broad categories of the acquired and/or congenitally disabled highlighted earlier. Some women in the former category may consider themselves too old to be “reinvented” after a disabling injury, while the latter may not have been actively encouraged into physical activity in the home or school settings in which they were socialized. Notably, Paralympic sport has mirrored the gender inequalities that have been inherent in modern sport since its inception in the nineteenth century. It is heavily male dominated, with fewer female participants than male and a lower proportion of women than men in the senior administration. Ultimately, both disability and gender can be seen to negatively impact and limit the choices and opportunities for women and girls with disabilities to participate in sport. These problems may arise because Paralympic sport is isolated from politics:

Sport is separate from disability politics. Disabled sportswomen are not connected with politics and disabled organisations are not interested in sport – the primary issues are jobs, health and housing, etc. So there is no support from disability organisations – I mean those run by disabled people who are tuned in to the political debates about disability and are making demands about equality in other areas. ... We need to politicize sport – we’re doing it in other areas, like the arts and theatre, but sport tends to be run by non-disabled people along the lines of non-disabled sport. And that’s probably not appropriate for most disabled people – and certainly not for most disabled women.

(Hargreaves, 2000, p. 195)

Of course, active athletes are training so hard that they have little energy left to engage in political debate. Sport for the disabled could benefit from a more radical presence of advocate athletes, and if this were supported by the wider feminist movement, the gendered nature of the Paralympics would be more readily highlighted. This is a difficult end to achieve, because the advocacy-driven disability movement that led to the development of radical disabled politics does not focus on bodies and therefore sport is seen as irrelevant. One of the ways in which the IPC is dealing with this issue is to establish the Women in Sport Committee, and this must be seen as a positive development. One of this committee’s chief mandates is the active encouragement of participation, from grassroots to elite performance. At the Paralympic Games, the value of women as role models should not be underestimated (Howe and Parker, 2012).

Some high-profile female athletes with disabilities have begun to exhibit the ability to empower themselves by embracing the narrative of “ability over disability” each time they compete. These Paralympians can exhibit the aesthetics of high performance: the skill, strength, and coordinated movement that come from a highly trained athletic body. There is an increased number of women with disabilities using the agency of their bodies in a confident manner, which suggests that they understand themselves in relation to the culture of Paralympic sport and their own identity (Howe and Parker, 2012). Of course, not all women with disabilities are in a position to challenge the widely held view that disability precludes women’s involvement in sport. A majority of disabled women lack power in their interactions with able-bodied women and men with disabilities.

This is a situation of which the IPC is well aware and its mission statement includes: “To
develop opportunities for women athletes and athletes with high support needs at all levels and in all structures. With this firmly on the IPC agenda, it is clear that more sociological research surrounding both women and HSNC athletes needs to be prioritized to explore more fully what is limiting participation among these groups.

**Mobility technologies**

This chapter now turns its focus toward technology, as this is something from which all bodies - able and disabled - can benefit. It is the sociological importance of movement technologies that interests coaches and athletes here.

The development of mobility technologies that are specifically designed for sport is a response to athletes' desire to perform with greater proficiency. Today many of the top para-athletes and their coaches work with leading wheelchair and prosthetics suppliers to ensure that their future success is based not only on their detailed and comprehensive training regimes, but on the synergy between their bodies and competitive technologies. Athletes who use mobility technologies such as racing chairs and prosthetic limbs are to a large extent captured in the imagination of the public. The technology and the incredible performances. The technology and the incredible performances. The technology and the incredible performances. The technology and the incredible performances.

To the outside world, the Paralympics are celebrated for the marriage of human and machine. As Charles (1998, p. 379) suggests: Technology and kinesiology are symbiotically linked. They have an mutually beneficial relationship. Technology advances, so does the quality of scientific research and information accessible to the field. As technology progresses and gains academic acceptance and credibility, technology and kinesiology are symbiotically linked. They have an mutually beneficial relationship. Technology advances, so does the quality of scientific research and information accessible to the field. As technology progresses and gains academic acceptance and credibility, technology and kinesiology are symbiotically linked.

As Shogun (1998, p. 272) comments, "When persons with disabilities use technologies that enable them to reach the highest potential of their abilities, they are able to participate in a meaningful way in society." Following this statement, it is clear that the field of high-performance sport (of which Paralympic Movement in developments in technologies associated with mobility, namely the wheelchair and prosthetic legs. Abled-bodied athletes rely on technologies in their day-to-day routines and appear less like advanced technology in comparison to racing wheelchairs and space-age prosthetic limbs. As Shogun (2001, p. 272) comments, "When persons with disabilities use technologies that enable them to reach the highest potential of their abilities, they are able to participate in a meaningful way in society."
movements within society generally, and on the field of play specifically.

**Coach’s Corner**

These technologies should be celebrated, but within limits. Not all Paralympians are able to take advantage of this technology and some may be in danger of being marginalized as a result of the fact that they do not engage in the use of mobility technologies.

Seymour (1998, p. 126) suggests that coaches and athletes need to avoid the pitfalls of assuming that involvement in high-performance sport has a similar impact on everyone: “It is undeniable that sport and physical activities provide a context for enjoyment, self-identity and competence, but unless the conditions and ideology of sport are challenged, women, and indeed many men, will continue to operate in a context that compounds their disadvantage.”

**Conclusion**

This chapter has attempted to highlight how coaches can use social scientific knowledge to give them an understanding of the context in which their athlete is trying to achieve excellence. Structural issues, such as classification, are central to Paralympic sport, but are also inextricably linked to individuals or agents within the Paralympic Movement, the most important of which are the athletes with whom coaches are working closely. Athletes’ bodies may vary with regard to degree of impairment and gender. Over 15 years ago, criticism was leveled at the IPC that in the past athletes were not of central concern to the movement:

for the Paralympic Movement lurks the danger of becoming top-heavy, of concentrating ever more energies and financial resources on fewer rather than on the equally deserving majority. The sensible chord of overall social responsibility and accountability should thus continue to be the guiding light of the Paralympic Movement. This does not always appear to be the case as concerns the ever-resource-hungry-elite-high-performance-sporting-system.

(Landry, 1995, p. 14)

One way in which the IPC has addressed these concerns is to have committees targeted at potentially marginal groups. The IPC Women in Sport Committee and the AHSNC have had a positive impact on assuring continued development of these important areas of the IPC and the Paralympic Games.

After reading this chapter, coaches will be able to use the sociological insight within it in order to better understand the culture of Paralympic sport, with the aim of helping to enhance athletes’ performance.

**References**


Chapter 7
Research needs for the development of evidence-based systems of classification for physical, vision, and intellectual impairments

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Introduction

The purpose of classification in Paralympic sport is to “promote participation in sport by people with disabilities by minimizing the impact of eligible types of impairment on the outcome of competition” (Tweedy and Vanlandewijck, 2011). If a classification system is to achieve this aim, each class within which each athlete competes should consist of athletes who all have impairments that cause approximately the same amount of disadvantage in the sport. This will create a structure for competition in which successful athletes will be those who have the most advantageous combination of skill along with anthropometric, physiological, and/or psychological attributes that have been enhanced to best effect. The athletes who succeed will not simply be those who have impairments that cause less disadvantage than their competitors (Tweedy and Vanlandewijck, 2011).

Classification that is not valid, or is not perceived to be valid, poses a significant threat to Paralympic sport. At the elite level, the legitimacy of an individual’s competitive success or athletic achievement can be significantly diminished by the perception that they are in the wrong class, with potentially

Coach’s Corner

- An understanding of current methods of classification is critical for coaches of Paralympic athletes because, as is sometimes said, “medals are decided during classification.”
- The involvement of coaches will be vital for the development of evidence-based methods of classification.
- The involvement of athletes is also critical for the development of evidence-based systems of classification. When coaches fully understand some of the assumptions made in current methods of classification, the methods required to address these assumptions, and the critical importance of athlete involvement, they are in the best position to encourage the athletes they know to take part in testing for the benefit of the whole Paralympic Movement.
Research needs for the development of evidence-based systems of classification

Adverse personal and financial consequences for the athlete. At the grassroots level, a classification system that is perceived to be unfair will discourage participation among people with disabilities, rather than achieve the goal of increasing it (Tweedy and Vanlandewijck, 2011).

The International Paralympic Committee (IPC) is the global governing body of the Paralympic Movement, as well as the organizer of the Summer and Winter Paralympic Games. The IPC recognizes the vital importance of transparent and defensible systems of classification, and in 2007 published the IPC Classification Code (International Paralympic Committee, 2007), which explicitly states a commitment to the development of evidence-based systems of classification (Section 15.2).

Coach’s Corner

Although recognition of the need for evidence-based classification has been an important step forward in Paralympic sport, initial efforts to develop such systems have proven problematic because, until that time, Paralympic classification had been largely atheoretical (Tweedy, 2002) and, as a consequence, there was no consensus regarding what constituted evidence-based classification or how it could be achieved. To address this issue, the “International Paralympic Committee Position Stand – Background and Scientific Principles of Classification in Paralympic Sport” was published in 2011 (Tweedy and Vanlandewijck, 2011). The aim of that paper, referred to from here forward as the Position Stand, was twofold:

- To “provide a theoretically grounded description of the scientific principles underpinning classification in Paralympic sport”; and
- “to define the term evidence-based classification and provide guidelines for how it may be achieved.”

Since its publication, the Position Stand has been cited in the peer-reviewed scientific literature more than 20 times, which, while modest when compared to many fields of scientific research, is encouraging given the historically low volume of research in Paralympic classification. While many of the articles citing the Position Stand explicitly aim to contribute to the development of evidence-based systems of Paralympic classification, evaluation of the research methods reported in those studies indicates that many are not consistent with the principles articulated in the Position Stand. Unfortunately, these inconsistencies limit the extent to which the research findings can contribute to the development of evidence-based classification systems. One of the aims of this chapter is to provide greater detail on key elements of research design and measurement methods required for the development of evidence-based classification, thereby assisting researchers to improve the effectiveness of classification-focused research.

Coach’s Corner

A second reason for expanding on the key principles of the Position Stand is the IPC initiative to establish three postdoctoral research fellowships in Paralympic classification, one at the University of Queensland (Australia) focused on the classification of physical impairments, one at Vrije Universiteit Amsterdam (the Netherlands) focused on vision impairment, and one at KU Leuven (Belgium) focused on intellectual impairment. Through this initiative, the IPC funds the salary of a research fellow, and the universities undertake to provide the research fellow with mentorship from senior researchers, supply research infrastructure (i.e., laboratory space, equipment, consumables, and administrative support), and source funding for research projects in Paralympic...
classification. The structure aims to facilitate the development of a concentration of expertise in each of the three areas so that the centers can provide practical leadership and innovation for classification research specific to each of the three impairment groups. Clearly, it is essential that research undertaken in each of these centers is consistent with the principles articulated in the Position Stand, and therefore this chapter will describe how the principles articulated in the Position Stand can be operationally translated into three programs of research that are conceptually aligned and will achieve the desired outcomes.

This chapter is divided into two sections. The first provides a brief overview of the structure of Paralympic sport, highlighting what sports must do to ensure that their classification systems are compliant with the requirements of the IPC. The second section provides a summary of how the principles articulated in the Position Stand can be operationally translated into programs of research, paying particular attention to important differences between physical, vision, and intellectual impairment.

**Overview of Paralympic sports**

While the sports contested at the Paralympic Games are fairly consistent, there is some variation across Games. For example, at the 2016 Rio de Janeiro (Brazil) Paralympic Games two sports – para-canoe and para-triathlon – were contested for the first time, while two other sports – football 7-a-side and sailing – were contested in Rio but will not be at the 2020 Tokyo Paralympic Games. Table 7.1 presents a total of 27 Paralympic sports comprising the 22 that were contested at the 2016 Rio Summer Games, and the five that will be contested at the 2018 Pyeongchang (Korea) Winter Games.

The organizations that govern the sports within which an athlete can compete in the Paralympic games are shown in Table 7.1. From the perspective of performing classification research, governing organizations are important, because they ultimately decide whether the research findings will be adopted in an effort to improve their classification system. Governing organizations can also contribute to the quality and relevance of research by providing researchers with a grounded understanding of how the sport is conducted, as well as assistance with the recruitment of research participants. For these reasons, researchers should always aim to develop close, cooperative working relations with the relevant governing organization.

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**Coach’s Corner**

Coaches are ideally positioned to provide researchers with a grounded understanding of how their sport is conducted and to assist with the recruitment of participants. It is no exaggeration to say that scientific research on classification cannot proceed without the support of coaches who are prepared to encourage their athletes to participate in classification research.

Persons with any one of ten different types of impairment are eligible to participate in Paralympic sport: vision impairment, intellectual impairment, hypertonia, ataxia, athetosis, impaired muscle power, impaired passive range of movement, limb deficiency, leg length difference, and short stature (Tweedy and Vanlandewijck, 2011). The final eight are collectively considered to be physical impairments (see Table 7.1). Although persons can have different types of vision and intellectual impairment, at present there are no separate classes to differentiate between those different types of impairment.

Each of the governing organizations listed in Table 7.1 has an official policy commitment to ensure that the classification system(s) for which they are responsible meet the requirements of the IPC Classification Code and, by implication, the Position Stand. However, the extent to which this commitment has been realized varies from sport to sport. For example, the IPC Classification Code and the Position Stand both require each Paralympic sport to develop its own classification system, referred to as *sport-specific classification* (International Paralympic Committee, 2007; Tweedy and Vanlandewijck, 2011). This requirement is based on the principle that an impairment of any given type, severity, and location may cause relatively little disadvantage in one sport, yet a significant
### Table 7.1
Sports for the 2016 Rio Summer Paralympic Games and the 2018 Pyeongchang Winter Paralympic Games. Governing bodies of each sport are presented, together with the impairment groups that are eligible to compete (physical, vision, or intellectual). Note that there are eight different types of physical impairment eligible for Paralympic sport: hypertonia (HT), ataxia (At), athetosis (Ath), muscle power (MP), range of movement (ROM), limb deficiency (LD), leg length difference (LLD), and short stature (SS). Sports eligibility varies across each of the eight types of physical impairment. However HT, At, and Ath are presented in a single column because they are all eligible to compete in the same sports.

<table>
<thead>
<tr>
<th>Paralympic sport</th>
<th>Governing body</th>
<th>PI</th>
<th>VI</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archery</td>
<td>World Archery</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Athletics</td>
<td>IPC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Boccia</td>
<td>Boccia International Sports Federation (BISFed)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Para-canoe</td>
<td>International Canoe Federation (ICF)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Para-cycling</td>
<td>International Cycling Union (UCI)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Equestrian</td>
<td>International Equestrian Federation (FEI)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Football 5-a-side</td>
<td>International Blind Sport Association (IBSA)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Football 7-a-side</td>
<td>Cerebral Palsy International Sport and Recreation Association</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Goalball</td>
<td>International Blind Sport Association (IBSA)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Judo</td>
<td>International Blind Sport Association (IBSA)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Para-triathlon</td>
<td>International Triathlon Union (ITU)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Powerlifting</td>
<td>IPC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Rowing</td>
<td>International Rowing Federation (FISA)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Table 7.1 (Continued)

<table>
<thead>
<tr>
<th>Paralympic sport</th>
<th>Governing body</th>
<th>Impairment group: Physical (PI), vision (VI), or intellectual (II)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HT, At, Ath</td>
</tr>
<tr>
<td>Sailing</td>
<td>International Federation for Disabled Sailing</td>
<td>✓</td>
</tr>
<tr>
<td>Shooting</td>
<td>IPC</td>
<td>✓</td>
</tr>
<tr>
<td>Swimming</td>
<td>IPC</td>
<td>✓</td>
</tr>
<tr>
<td>Table tennis</td>
<td>International Table Tennis Federation (ITTF)</td>
<td>✓</td>
</tr>
<tr>
<td>Table tennis (ITFF)</td>
<td>World ParaVolley</td>
<td>✓</td>
</tr>
<tr>
<td>Wheelchair basketball</td>
<td>International Wheelchair Basketball Federation</td>
<td>✓</td>
</tr>
<tr>
<td>Wheelchair fencing</td>
<td>International Wheelchair and Amputee Sports Federation (IWAS)</td>
<td>✓</td>
</tr>
<tr>
<td>Wheelchair rugby</td>
<td>International Wheelchair Rugby Federation (WRF)</td>
<td>✓</td>
</tr>
<tr>
<td>Wheelchair tennis</td>
<td>International Tennis Federation (ITF)</td>
<td>✓</td>
</tr>
<tr>
<td>Alpine skiing</td>
<td>IPC</td>
<td>✓</td>
</tr>
<tr>
<td>Ice sledge hockey</td>
<td>IPC</td>
<td>✓</td>
</tr>
<tr>
<td>Nordic skiing</td>
<td>IPC</td>
<td>✓</td>
</tr>
<tr>
<td>Para-snowboard</td>
<td>IPC</td>
<td>✓</td>
</tr>
<tr>
<td>Wheelchair curling</td>
<td>World Curling Federation</td>
<td>✓</td>
</tr>
</tbody>
</table>

Sports for 2018 PyeongChang Winter Games (N=5)

Total number of sports available: 23 (PI), 23 (VI), 23 (II), 13 (Nordic), 6 (Para-snowboard), 13 (Wheelchair curling), 3 (Wheelchair fencing)

1 Nordic skiing includes the disciplines of biathlon and cross-country skiing.
disadvantage in another. For example, a through-hand amputation is likely to have a bigger impact on swimming performance than it would when running a marathon. Most Paralympic sports have classification systems developed specifically for their sport, with the notable exception of sports that are designed for athletes with vision impairment, where essentially the same system is used as the basis for classification. In brief, for those 13 sports contested by athletes with vision impairment, both the determination of eligibility and the subsequent allocation of competition class (if relevant) are based on the same level of visual acuity (a measure of clarity of vision) and/or visual field (a measure of peripheral vision), irrespective of the sport. In this regard, these classification systems are not sport specific and so the sports are not compliant with the Classification Code or the Position Stand.

Coach’s Corner

Coaches and athletes can provide researchers with important information describing the relative impact of a given vision impairment on different sports.

As a result, one of the research priorities for the classification research and development center for vision impairment is to facilitate the development of sport-specific systems for classifying vision impairment. For example, it might be reasonable to expect that due to the contrasting visual demands of different sports, even a mild level of impairment to visual acuity could have a significant impact on performance in some sports (e.g., football and alpine skiing), but have less impact on others (e.g., swimming and judo). Sport-specific classification systems would reflect the relative importance of visual acuity in these sports.

Another example of discrepancies between what is required by the Classification Code and the classification systems used by some sports is that, while the information in Table 7.1 is largely accurate, some of the information regarding eligible impairment types for certain sports had to be inferred, because a small number of sports do not describe eligibility in terms of impairments (as required by the Classification Code) but instead refer to health conditions (e.g., spinal cord injury, cerebral palsy, amputation). Unfortunately, these descriptors are not only inconsistent with the Classification Code, they are also inaccurate and misleading, because the sports concerned do not restrict participation to people with these health conditions.

In summary, there are a range of Paralympic sports, and the impairment types that are eligible for these sports vary considerably. Although the sports have a policy commitment to implement classification systems that are Classification Code compliant, there are clear examples of discrepancies between currently used classification systems and the requirements of the Classification Code. In fact, the aspect of Classification Code compliance that is most challenging, and that no Paralympic sport has fully achieved, is the requirement for a system of classification to be evidence based. The principal reason for this aspect of non-compliance is that the evidence required to develop such systems is not available and, consequently, research is required. Principles for the development of evidence-based systems of classification are outlined in the IPC Position Stand on classification. The remainder of this chapter describes how these principles can be applied to develop evidence-based systems of classification for physical, vision, and intellectual impairments.

Developing evidence-based systems of classification for physical, vision, and intellectual impairments

In the past there has been uncertainty about the level of research that is required for a sport to develop an evidence-based system of classification. In an effort to overcome this, Figure 7.1 presents a flow diagram incorporating six boxes with a solid outline (labeled Step 1, Step 2, Step 3a, Step 3b, Step 4, and Step 5), each of which represents an essential step required for developing evidence-based systems of classification. These steps are based on the principles articulated in the Position Stand and elaborate on a previously published schematic that focused on the process necessary for the classification of physical impairments (Tweedy et al., 2014).
Chapter 7

Step 1: Identify target sport and impairment type/s to be classified.

Step 2: Develop theoretical model of the determinants of sports performance.

Step 3a: Develop valid measures of impairment/s (i.e., specific to the impairment; quantitative; reliable; precise; parsimonious; training resistant; and ratio scaled).

Step 3b: Develop standardised, sport-specific measure/s of determinants of performance.

Step 4: Assess the relative strength of association between valid measures of impairment and sport-specific measures of performance determinants in order to identify the measures of impairment that account for a significant and independent portion of the variance in performance.

Step 5: Use outcomes from Step 4 to determine minimum impairment criteria, number of classes and class profiles.

Figure 7.1 Schematic representation of research required for the development of evidence-based systems of classification. The boxes with the solid outlines (Steps 1–5) are essential. The boxes with dashed outlines (QA1–QA3) are not essential to every research program, but are generally important quality assurance (QA) measures.

In general, the process is sequential, beginning at Step 1 and requiring the completion of each step before work on the next step in the process can commence. Step 1 requires researchers to identify the sport on which the research will focus, as well as the impairment type(s) that the research will aim to classify for that sport. Step 2 requires development of a theoretical model of the determinants of performance in the selected sport. The next two steps – 3a (develop valid measures of impairment) and 3b (develop standardized, sport-specific measures of determinants of performance in that sport) – do not have to occur in any particular order. However, both must be completed before undertaking Step 4, in which an assessment of the relative strength of association is made between the valid measures of impairment and sport-specific measures of performance determinants. The final step, Step 5, requires an analysis of the outcomes obtained in Step 4 and, depending on the analysis conducted, the results can inform the establishment of an evidence-based system for setting the minimum impairment criteria and the most appropriate number of sport classes, as well as detailed methods for allocating athletes to classes based on how much their impairment is likely to affect performance in the sport of interest. These new, evidence-based systems of classification will provide a defensible, transparent, and reproducible means of achieving the aim of classification: to minimize the impact of an eligible impairment on the outcome of competition.

Coach’s Corner

Coaches and athletes have an excellent understanding of the relative contribution of different sport-specific determinants of performance and can therefore make a valuable contribution to the development of a valid theoretical model of performance determinants.
The boxes with dashed outlines (labeled QA1–QA3) present quality-assurance (QA) measures – measures that are not always essential but that will, if addressed, enhance the veracity of the research or the validity of the classification process, or enable research findings to be more readily translated into practice. The remainder of this chapter seeks to provide more detail about the procedure outlined in Figure 7.1.

**Step 1: Identify target sport and impairment types to be classified**

The task of classifying impairments according to how much difficulty they cause in a given Paralympic sport will usually begin with the identification of a target sport. Having done this, target impairments should be identified. As indicated in box QA1, research that will make the most direct contribution to the development of evidence-based classification in the current Paralympic sports will investigate impairments that are:

- selected from the 10 impairment types that are eligible for Paralympic sport; and
- eligible for the target sport (determined by each sport).

Table 7.1 should provide researchers with guidance for this first step, as it presents the 10 impairment types that are eligible for Paralympic sport, along with the impairment types that make an athlete eligible for inclusion in each of the Paralympic sports.

Table 7.1 should provide researchers with guidance for this first step, as it presents the 10 impairment types that are eligible for Paralympic sport, along with the impairment types that make an athlete eligible for inclusion in each of the Paralympic sports.

Outcomes from studies that do not meet both of these criteria will make a less direct contribution toward the development of evidence-based classification, because additional approval processes will be required before implementation of outcomes can be considered. For example, West et al. (2014) recently published a study investigating autonomic cardiovascular control in Paralympic athletes with spinal cord injury. The study demonstrated that neurological-level and sympathetic skin responses provide the optimal combination of assessments to identify those at risk of abnormal cardiovascular control, a finding of unquestionable scientific and medical value. On the basis of these findings, the authors advocate incorporation of autonomic testing in the classification of athletes with spinal cord injury. However, impaired cardiovascular control is not one of the ten impairment types that are eligible for Paralympic sport (see Table 7.1). Consequently, before such a recommendation can be considered, the impairment types that are eligible for Paralympic support would need to be expanded to include cardiovascular control, and one or more of the organizations governing the 27 Paralympic sports would need to include impaired cardiovascular function among the impairment types eligible for their sport. The political and administrative processes required to realize such changes are likely to be considerable and positive outcomes are by no means guaranteed. Consequently, researchers who wish to make the most direct contribution to classification in the existing Paralympic sports and avoid political/administrative uncertainty can do so by choosing to investigate impairment types that meet the criteria in QA1.

The task of identifying impairments that meet the criteria in QA1 is complicated to some extent because, as pointed out in the previous section, some sports list health conditions rather than impairment types. Other factors that complicate the identification of impairment types that are eligible for certain target sports include the following:

- The use of poorly defined descriptors such as “les autres,” a French term that literally means “the others” and was used to classify athletes with a “locomotor disability” who were not eligible to be classified in the systems used for people with spinal cord injury, cerebral palsy, or amputation. The term was in common use within the Paralympic Movement prior to publication of the Position Stand and specification of the ten eligible impairment types. In the interests of clarity of communication and accuracy, terminology used in classification systems should be aligned with the Position Stand and the term “les autres” should no longer be used.
- The practice of naming impairment types that are eligible in theory but are, for all practical purposes, excluded from the sport. At a superficial level, sports that indicate that people with a wide range of impairments are eligible appear to be more inclusive. However, if a sport identifies an
impairment type as eligible, but does not describe methods for how to classify that impairment, inclusion is in name alone. For example, wheelchair tennis identifies short stature as an eligible impairment type (see Table 7.1), but the classification manual provides no guidance on how to classify athletes with short stature for wheelchair tennis. In fact, there are very few people with short stature using wheelchairs, so it is questionable whether the development of methods for classifying this group is warranted.

As Paralympic sport matures, the quality of classification documentation will improve and the significance of the issues identified in this section is likely to diminish. However, for the foreseeable future, researchers who wish to have an impact on the development of evidence-based systems of classification should work in close consultation with the administrators of the target sport to ensure that athletes with impairment types selected for investigation have genuine competitive opportunities in the target sport.

**Step 2: Develop a theoretical model of the determinants of sports performance**

This step ensures that researchers adopt a systematic approach to understanding what factors are most important for elite performance in the target sport. Outcomes from this step provide information that is critical for Steps 3a and 3b in terms of establishing which measures of impairment and performance are required. As indicated in the name of this step, there are two broad tasks:

- Determine how overall sports performance is assessed and identify the key activity or activities that an athlete must perform.
- Identify the factors that determine overall performance in that sport (or its key activities). Typically, factors would include neuromusculoskeletal factors (e.g., strength of individual muscle groups, range of movement required for sports-specific movement), anthropometric factors, physiological factors, visual factors, psychological factors, technical factors, and tactical factors.

**Overall sports performance assessment and identification of key activities**

The complexity associated with determining sport performance varies considerably from sport to sport. The examples here provide a framework for approaching this task, starting with powerlifting, a sport in which the task is relatively easy, and ending with wheelchair rugby, one of the more challenging sports.

Powerlifting (bench press) represents a sport in which the assessment of performance is rather simple. Performance is based on mass lifted – better powerlifting performance is achieved by lifting greater mass, a one-dimensional, quantifiable outcome. The athlete only performs one activity: the bench press. In contrast, in 100-meter freestyle swimming there are a number of discrete activities involved during a race that make the determination of sport performance more complex. Performance is based on the time taken to swim two laps of a 50-meter pool – better swimming performance is achieved by a shorter swimming time, an outcome that is, like powerlifting, one-dimensional and quantifiable. However, unlike powerlifting, a swimmer must perform several distinct activities during a swimming race, including propulsive activities (dive, swimming stroke, and the tumble turn) and drag-reducing activities, also known as streamlining (Oh et al., 2013). It should be noted that because overall sports performance can be quantified (time for 100 meters), it is possible to conduct research to quantify the relative importance of each of the component activities. For example, research can establish the relative contribution of the dive, the swimming stroke, and the tumble turn to overall swimming time. The role of such research in the development of evidence-based systems of classification is discussed further later in the chapter.

The assessment of performance in team sports can be much more complex. For instance, the assessment of performance in wheelchair rugby is, fundamentally, relative – a team performs well if it
scores more points than the opposition. However, classification applies to individual players and the performance of individual players is more difficult to assess, with each player making a distinct but indeterminate contribution to team performance. Consequently, there is no single, quantifiable measure of the performance of an individual player. Identification of the key activities that contribute to individual player performance (e.g., ball handling, catching, accelerating, and turning/mobility) is relatively straightforward; however, because individual player performance cannot be quantified, it is more difficult to establish the relative importance of these activities for individual player performance. Outcomes from this first broad task in Step 2 are required to undertake Step 3b: to develop standardized, sport-specific measures that, individually or collectively, determine performance in the target sport.

Identifying the factors that determine overall performance

The second of the two broad tasks required in Step 2 is to identify the factors that facilitate overall sports performance or performance of the key activities. A comprehensive model of determinants of sports performance would include physical, visual, and intellectual/cognitive factors, as well as anthropometric determinants and psychological determinants (e.g., motivation or confidence). As the process evolves, greater emphasis will be placed on performance determinants that relate directly to the impairment type being investigated. For example, having determined that the sport of alpine skiing requires an athlete to perform the activities of starting, skiing straights, and taking corners, a research team seeking to develop an evidence-based system of classifying the impact of vision impairment on the sport will begin to focus predominantly on the visual determinants of those activities. For example, the ability to see and be guided by the position of the flags might be identified as an important determinant of cornering performance.

Researchers aiming to develop evidence-based systems for classifying the impact of intellectual impairment on sports may benefit from focusing on three broad areas of sports performance in which intellectual capacity plays a significant role – the tactical requirements of overall sports performance; the technical requirements of performing the key activities; and the psychological requirements of dealing with a training regime and the competitive environment – because it is these aspects that are most likely to be influenced by intellectual impairment.

Methods of varying sophistication can be used to develop a theoretical model of determinants. The foundation for developing the model of performance determinants should be a review of the scientific literature. In many instances, research in able-bodied sport is relevant, providing a very sound description of ideal performance in a given sport, an important starting place. For example, two seminal reviews of running biomechanics in non-disabled runners provide a very good description of the range of movement required in the joints of the lower limb for high-performance running (Mann and Hagy, 1980; Novacheck, 1998); the findings they report have been corroborated by more recent studies (Miller et al., 2012; Nicola and Jewison, 2012). In relation to wheelchair sports, studies describing performance determinants of athletes who have disabilities, who are skilled in the sport of interest but who have unimpaired arms, trunk, and pelvic stability, provide the best model (e.g., people with a cauda equina injury). It is worth noting that this process can be challenging in sports where there is no able-bodied equivalent (e.g., goalball), or if the modified version of the sport is very different to the able-bodied equivalent (e.g., triathlon and para-triathlon).

Because Paralympic sport comprises physical, visual, and intellectual impairments, it is the physical, visual, and intellectual determinants of performance in various sports that are of key interest in relation to developing evidence-based systems of classification. Unfortunately, scientific literature in these areas is still relatively scarce. To overcome this paucity, qualitative methods such as the Delphi process (Clayton, 1997) or roundtable expert meetings comprising Paralympic athletes, sport scientists, classifiers, and coaches can provide researchers with a time-efficient, multi-professional indication of the key determinants for a particular sport.
When attending expert meetings with researchers from Olympic and Paralympic sports, classifiers and sport-technical officers, athletes, and coaches are in an ideal position to provide insight in the relative contribution of the different determinants of sport-specific performance.

While the overall volume of research in the area is relatively small, in the field of vision impairment a number of researchers have successfully applied environmental manipulations and/or simulation techniques to evaluate the visual determinants of sports performance. For example, environmental constraints that are thought to provide important visual information can be manipulated (e.g., the position of the “T” at the bottom of a swimming pool to signify a turn, or the position of lanes to guide running direction in athletics). If the change in the environmental constraint alters performance, then this indicates that the visual information is important and that vision impairment may adversely affect performance. Simulation techniques entail simulating a vision impairment in order to manipulate the quality of the visual information and establish whether a simulated impairment alters performance. For instance, spectacle lenses or contact lenses can be used deliberately to blur the vision of athletes to determine whether simulated impairment decreases performance, and, if so, the level of impairment necessary to alter performance (Mann et al., 2007, 2010). Moreover, gaze-contingent displays that change what an observer sees based on where they are looking can be used to examine whether restrictions to peripheral vision alter performance in sport-specific tasks (Ryu et al., 2013, 2015). Unfortunately, these techniques of environmental manipulation and/or simulation techniques cannot readily be used to identify physical or intellectual determinants of sports performance.

Results from simulation studies that use non-disabled participants should be interpreted cautiously for two reasons. First, a person with a disability will be considerably more familiar with performance under impairment-constrained conditions than a non-disabled participant, and therefore results may overestimate the extent to which the impairment will have an impact on the performance of a person with a disability. Secondly, a non-disabled person has had the advantage of acquiring the skills necessary for the sport without the negative influence of impairment, and therefore results may underestimate the extent to which impairment will have an impact on the performance of a person with a disability, particularly a congenital impairment. Outcomes from this second task are required to undertake Step 3a, described in the next section.

**Step 3a: Develop valid measures of impairment(s)**

Having identified both the impairment(s) to be classified (Step 1) and the relevant physical, visual, or intellectual determinants of sports performance (Step 2), appropriate measures of the impairment are required. Before proceeding, it is important to recognize that the term “measures of impairment” is used for ease of communication, but that, of course, it is not possible to measure a loss or absence directly. Rather, impairment must be inferred based on knowledge of intact, unimpaired body structures and functions. To illustrate, it is not possible to measure directly the length of a lower leg lost by a bilateral, transtibial amputee. However, methods for inferring the loss based on the length of other body segments – sitting height, thigh, upper arm, and forearm – have been published (Canda, 2009). This principle applies to all “measures of impairment.”

The measurement properties required by measures of impairment that will be valid for the purposes of Paralympic classification are described in the Position Stand. In summary, measures should be:

- specific to the impairment of interest (i.e., directly measure one of the ten eligible impairment types)
- reliable
- precise
- quantitative
- parsimonious (i.e., account for the greatest possible variance in sports performance)
• training resistant
• ratio scaled

It should be noted that the final measurement property – ratio scaled – was not specified in the Position Stand, but it has become apparent that it is critical. Reasons for its inclusion are described in detail in the section on impaired muscle power. The remainder of this section considers measurement issues relevant to each of the ten eligible impairment types and, where possible, provides examples of recent advances and future directions. The structure of this section reflects the requirement for impairment specificity, with each of the impairment types receiving specific consideration. The advantage conferred by parsimony is best illustrated in the section on impaired range of movement. The requirement for measures to be, as far as possible, resistant to the influence of training is a measurement feature that is important for minimizing the mediating influence that training can have on the impairment (performance relationship) and is described in more detail in the section describing Step 4.

**Impaired muscle power**

Athletes with impaired muscle power are eligible to compete in 23 of the 27 Paralympic sports, and therefore methods for its assessment are critical. Currently, sports that assess muscle power do so using manual muscle testing (MMT), in which the strength of an individual muscle action (e.g., elbow flexion and knee extension) is assigned a grade from 0 (no voluntary muscle contraction) to 5 (normal strength through normal anatomical range of movement) according to their capacity to overcome gravity and/or manual resistance applied by the tester (Tweedy et al., 2011). The widespread use of MMT in current classification systems is due to a number of inherent advantages: it is widely understood and utilized in clinical practice and, because it does not require any instrumentation, is inexpensive and space efficient. Although inter-rater reliability is difficult to achieve, the absence of a viable alternative measure means that the use of MMT in current systems of classification is defensible, and indeed necessary.

However, MMT methods are based on an ordinal scale, meaning that although points on the scale are ordered from smallest to largest, the relative difference between points on the scale is variable or not known. For example, in MMT it cannot be assumed that a Grade 2 muscle is twice as strong as a Grade 1 and half as strong as a Grade 4. Consequently, ordinal-scale measures cannot validly be incorporated into research projects that aim to develop evidence-based systems of classification. This is because, as indicated in Step 4 of Figure 7.1, evidence-based systems of classification require quantification of the relative strength of association between different muscle actions in a given sporting movement. Because the relative differences between points on an ordinal scale are not known, outcomes from an ordinal-scale measure of impairment cannot be used to quantify the relative strength of association between impairment and performance.

To address this issue, a battery of isometric strength tests with the measurement properties required for the development of evidence-based classification has been published in the sport of athletics (Beckman et al., 2014). To illustrate how such measures can be used in the development of evidence-based systems of classification, a study evaluating the effect of trunk strength on wheelchair track acceleration used a novel isometric strength protocol (rather than MMT) to measure isometric trunk-flexion strength. Results demonstrated that trunk strength is not dominant in wheelchair sprinting events, accounting for 7–10% of the variance in performance of a wheelchair track start (Vanlandewijck et al., 2011). Such analyses are critical to the development of evidence-based methods of classification and are only possible when ratio-scaled measures of strength are obtained.

There are a range of other issues that must be considered in the development of strength measures that will be valid for the purposes of Paralympic classification, including the training responsiveness of measures of strength, and the most appropriate method of controlling for the influence of body size. Unfortunately, it is beyond the scope of this chapter to consider them further, but they
are described in greater detail elsewhere (Beckman et al., 2014).

Impaired range of movement

Currently, goniometry is the measurement method most commonly used to assess impaired range of movement in Paralympic classification. Like MMT, goniometry is a suitable and defensible method of impairment assessment in current systems of classification, because it requires minimal equipment and is widely understood and practiced. Additionally, when compared to MMT, goniometry has the advantage of being ratio scaled and this attribute would make it a defensible choice for researchers aiming to develop an evidence-based method for classifying impaired range of movement. However, goniometry would not be an “optimal” measure of impairment for classification research, because acceptable inter-rater reliability is difficult to achieve, and conventional joint-by-joint goniometry is not parsimonious (i.e., each individual measure in a conventional joint-by-joint assessment is likely to account for a relatively small amount of the variance in performance for most sports).

The development of measures that reflect range of movement in more than one joint will enhance parsimony. For example, a recent study has described novel measures of range of movement for running (Connick et al., 2015). One of the measures described – the heel draw test – is presented in Figure 7.2. The measure is parsimonious because it captures both available knee flexion and hip flexion within a single measure. Furthermore, its development was based on research indicating that optimal running performance depends on simultaneous knee and hip flexion during the mid-swing phase of running, resulting in a posture that is similar to the end position in the heel draw test (see Figure 7.2).

Ataxia and athetosis

Coordination can be defined as the ability to execute voluntary movements rapidly, accurately, and fluently (O’Sullivan et al., 2014). Based on this definition, the terms ataxia and athetosis refer

Figure 7.2  (A) Comparison of hip and knee flexion at mid-swing phase of the running cycle. Reproduced with permission of Sean Tweedy. (B) Comparison of hip and knee flexion at the end point of the heel draw test. Reproduced with permission of Mark Connick.
to specific types of impaired coordination: ataxia referring to voluntary movement that is unsteady, uncoordinated, or clumsy; and athetosis referring to involuntary movement and posturing that affect postural stability and dynamic movement. Although coordination is routinely assessed for classification in a range of Paralympic sports, the methods used are often qualitative or otherwise lacking key measurement properties required for the development of evidence-based systems of classification. Figure 7.3 presents a method for assessing impaired coordination (Connick et al., 2015) that has the measurement properties necessary for developing evidence-based systems of classification for impaired coordination. In summary, the participant is seated in front of two touch-sensitive tapping plates, each designed to register contact and with a target area marked in the middle. The participant is asked to tap each of the plates alternately in the target area as rapidly and accurately as possible for 15 seconds. Movement time is defined as the time between one contact and the next. The average movement time provides a ratio-scaled measure of the participant’s ability to move rapidly and accurately.

Two plates can be used to assess single-limb coordination (upper limb or lower limb) and four plates can be used to assess inter-limb coordination by asking the participant to perform reciprocal tapping tasks simultaneously with two limbs. Tapping may be in phase (an action similar to wheelchair pushing) or out of phase (an action similar to running). Discrete aiming tasks may be more appropriate than reciprocal tapping tasks when sports movements are not cyclical (e.g., in throwing events).

**Hypertonia**

Hypertonia is the least straightforward of the physical impairments because its measurement can be problematic and there is some evidence that the relationship between measured hypertonia and activity limitation is not strong, particularly for gross motor tasks (Ada et al., 1998, 2006). However, it is well established that hypertonia is associated with reduced selective muscle strength, as well as impaired active range of movement (due to contracture and/or muscular co-contraction) and incoordination due to loss of selective motor control (Sanger et al., 2003; Taylor et al., 2013). Development of measures that reflect reduced selective muscle strength, active range of movement, and/or impaired coordination will all help to provide an index of hypertonia severity. For example, a recent study demonstrated that average movement time for a lower-limb reciprocal tapping task was significantly lower for a sample of non-disabled runners than it was for a sample of 13 runners with brain impairment, 12 of whom had hypertonia (Connick et al., 2015).

**Limb deficiency, leg length difference, and short stature**

These three impairments are considered collectively because, according to the International Classification of Functioning Disability and Health, they are all impairments of structure (i.e., impairments of anatomical body parts such as organs and limbs). This is distinct from the other seven Paralympic impairment types, which are impairments of function (i.e., impairments of physiological functions of body systems). From a measurement perspective, this distinction is important because all of these impairments of structure can be measured in centimeters/inches using standard,
accepted techniques that satisfy the measurement properties identified earlier. A particular advantage inherent to these measures of structure is that they are not training responsive (i.e., they do not change in response to rigorous, sport-specific training). Consequently, there is relatively little developmental work required for measures of these three impairment types.

Vision impairment

Only two types of visual function are currently assessed: visual acuity and visual field. On the basis of these measures, eligible athletes are generally allocated into one of three possible classes irrespective of the sport. In order to move toward an evidence-based system of classification, research is required that identifies the aspects of vision that are likely to be important for a particular sport. Conducting this exercise across all 13 Paralympic sports in which people with vision impairments compete is likely to reveal a wider range of visual parameters or functions (in addition to, or instead of, visual acuity and fields) that may have an impact on sport performance and so will require an appropriate method of measurement. For instance, dynamic visual acuity (the ability to perceive a moving target accurately) might prove to be an important determinant of performance in sports like alpine skiing and cycling where the visual environment is not static. Similarly, some visual conditions make the eyes more sensitive to light and so light sensitivity could be a predictor of performance in sports played outdoors. Although measures of functions such as dynamic visual acuity and light sensitivity are available, unfortunately they have typically been developed to determine threshold levels of visual impairment in populations who do not possess vision impairment. This means that there is likely to be a relative paucity of valid tests that are suitable for determining thresholds in people with low vision. As a result, for some visual parameters new tests might need to be developed and validated.

Intellectual impairment

General intelligence is not a one-dimensional static measure but a very broad construct consisting of various cognitive abilities, such as short-term memory, domain-specific knowledge, and reaction and decision speed. Only a small subset of these cognitive abilities is relevant for sports performance. These are referred to collectively as “sports intelligence.” Sports intelligence, clustering all cognitive and metacognitive abilities that may have an impact on sport performance, can be measured generically and sport-specifically. Generic sports intelligence measures memory and learning, executive functioning, visual perception, fluid intelligence, and processing speed in a non-sport-specific way. These cognitive and metacognitive abilities are present in different sports to different magnitudes and proportions. It is assumed that a low score on the generic sports intelligence test implies a cognitive disadvantage in any sport with a significant cognitive load. In Figure 7.4, the “Memory Corsi Blocks” test is explained for illustration.

Box QA2, shown in Figure 7.1, presents three important threats to the validity of impairment measures: ecological validity, effort dependence, and interaction between impairments.

Ecological validity

If an athlete is assessed using an ecologically valid test, then the results of an assessment conducted during classification will accurately reflect the results that would be obtained if the test were conducted under the conditions of competition. If results obtained during testing for classification are significantly different from those that would be
obtained under competition conditions, then ecological validity is threatened.

The issue of ecological validity is relevant for a range of impairment measures: hypertonia measured under climate-controlled conditions may increase in the cold conditions experienced in winter sports, and measures of intellectual impairment may be different under standardized testing conditions when compared to the competitive pressures in a Paralympic final event for a gold medal. However, ecological validity arguably poses the greatest threat to measures of vision impairment. This is because light conditions can have a major impact on measures of vision impairment. These conditions are generally standardized during classification, but can vary considerably and unpredictably in the outdoor environments where many sports are contested (e.g., bright sunlight, cloudy, and night competition under artificial light). If changed light conditions had the same impact on all people with vision impairment, the threat would not be particularly significant. Unfortunately this is not the case, because the changes in lighting can adversely affect some types of vision impairment more than others. For instance, persons with ocular albinism are very sensitive to light and so their vision may be relatively good in low light, but will deteriorate in bright light to an extent much greater than that experienced by most other people. Similarly, athletes with visual conditions that have an impact on the ability to distinguish contrast (e.g., cataracts and corneal dystrophies) will be more affected than other athletes by low-contrast conditions, such as when there is fog, a common occurrence in alpine sports. Research that quantifies the effect of these types of changes (e.g., brightness or contrast) will provide an indication of whether this theoretical threat to validity has practical significance. Where research indicates that changes in lighting are of practical significance, further research may be required to develop methods for adapting the standard tests of vision to account for sensitivity to these environmental changes.

Effort-dependent tests
Tests that are only valid if the person being tested gives maximum effort pose a second significant threat to validity. The impairments of structure – limb deficiency, leg length difference, and short stature – are not exposed to this threat because they do not require any active effort from participants. Participants must comply, but no voluntary effort is required. Evaluation of a passive range of movement is also relatively immune to this threat: participants must voluntarily relax in order to allow their body segments to be passively taken through the available range, but no effort is required. However, the validity of assessments of the remaining six impairment types (hypertonia, ataxia, athetosis, muscle power, vision impairment, and intellectual impairment) all depend on participants to “do their best.” The practical implication of this threat to validity is that athletes can deliberately underperform on these tests and effectively exaggerate the severity of their impairment.

Coach’s Corner
Coaches can play an important role in assisting athletes who have a combination of impairments to choose a sport and/or a classification system that is best suited to their impairment profile.

The practice of underperforming on tests, known as intentional misrepresentation of abilities (IM), is sometimes attempted by athletes who aim to gain an unfair competitive advantage by being placed in a class with athletes who have more severe impairments than they do (International Paralympic Committee, 2007). While athletes found guilty of IM may be severely sanctioned, there are no objective methods for detecting IM, so cases are difficult to prosecute. Development of reliable, precise, ratio-scaled measures of impairment would facilitate research into the development of objective methods for detecting IM. For example, a conference paper by Deuble et al. (2015) described how Fitts’ Law might be applied to detect the intentional exaggeration of impaired coordination on a reciprocal tapping task using the tapping plates described previously (see Figure 7.3).

Interaction between impairment types
Many athletes are principally affected by one impairment type (e.g., limb deficiency in unilateral
lower-limb amputees and muscle power in people with low spinal cord injuries). However, many athletes are affected by multiple impairment types, and they can be divided into three main groups:

- **Athletes with a health condition that causes an eligible impairment type together with non-eligible impairment types.** Athletes with SCI above the sixth thoracic segment have reduced cardiac sympathetic drive, and those above the first thoracic segment have no sympathetic drive. Although reduced sympathetic drive reduces work capacity, cardiovascular impairments are not eligible impairment types and are therefore not classified in Paralympic sport. Under the current Paralympic sports structure, there is no scientific method for controlling for the interaction between eligible and non-eligible impairment types.

- **Athletes affected by more than one eligible impairment type.** For example, this is prevalent among athletes with cerebral palsy, traumatic brain injury, and spina bifida with hydrocephalus. All of these health conditions affect the brain and result in more than one of the following impairment types: hypertonia, ataxia, athetosis, impaired muscle power, and impaired range of movement. It is likely that there will be an interaction between these impairments, such that their combined impact on sports performance will be greater than the sum of each impairment type’s individual impacts. One administrative measure that can mitigate this threat is to use a competitive structure in which people with similar combinations of impairments compete together (e.g., athletes with cerebral palsy, traumatic brain injury, and spina bifida all competing together). Given the complexity of this issue and the relatively immature state of research in Paralympic classification, the prospect of a scientific solution to this issue seems remote.

- **Athletes with any combination of physical impairment, intellectual impairment, and vision impairment.** As with the previous example, such combinations are more prevalent among athletes with health conditions affecting the brain. According to the current structure of Paralympic sport, sport class is only allocated based on the activity limitation caused by one of the three impairment groups. For example, runners with cerebral palsy (spastic hemiplegia) who also have a vision impairment must choose whether they will compete against athletes with a physical impairment or a vision impairment. If they choose competition for people with physical impairments, they will be allocated a sport class based on the impact that their spastic hemiplegia has on running performance, and the allocation will not be adjusted because of the athlete’s vision impairment. If they choose competition for people with vision impairment, their class will be allocated based on vision impairment, with no consideration given to the effect of spastic hemiplegia. Under the current Paralympic sports structure, there is no scientific method for controlling for the interaction between physical, vision, and intellectual impairment types.

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**Step 3b: Develop standardized, sports-specific measure(s) of performance**

Having identified both the target sport (Step 1) and the key activity or activities that an athlete must perform (Step 2), researchers are in a position to address Step 3b; that is, to develop standardized, sport-specific measures that individually or collectively quantify performance. In the Position Stand, such measures are referred to as measures of activity limitation (Tweedy and Vanlandewijck, 2011).

The selection of appropriate test(s) of performance for a given sport should be guided by three principles:

1. The test outcome should be highly predictive of overall performance in the sport.
2. The outcome measure should be sensitive to differences in the measures of impairment.
3. Factors that are not classified should have minimal influence or should be strictly controlled for using an appropriate experimental design.

Table 7.2 provides examples of possible standardized, sport-specific measures of performance. The aim of the tests in the table is to illustrate how the three principles can be applied; they are not meant to be prescriptive or to provide a “recipe for research” in the sports identified.

In Example 1 (the first row), overhand seated throw distance using a 500 g ball has been selected
as a sport-specific measure of performance for seated javelin. There is evidence to indicate that overhand throw distance is predictive of javelin performance, so in this regard the test adheres to Principle 1 (Spathis et al., 2015). Note that the specificity of the test is improved by selecting a ball of approximately the same weight as the javelin. Additionally, it could be reasonably expected that when athletes with impaired upper-limb/trunk-muscle power perform this activity to the best of their ability, then increased impairment will be associated with decreased throw distance. In this regard, the test is consistent with Principle 2. Finally, adherence to Principle 3 is achieved by basing the test on an overhand throw rather than a javelin throw. Specifically, the overhand throw is a fundamental motor skill usually acquired during normal growth and development, whereas considerable skill and experience are required to throw a javelin competently. If the javelin throw was used as the performance test, javelin throwing proficiency may have too great an influence on the test outcome, such that an athlete with high muscle power impairment who was highly skilled at the javelin might throw further than a person with less muscle power impairment who was a less proficient javelin thrower.

Tests that aim to reflect the impact of intellectual impairment on different sports performance are presented in Example 2. The test selected for evaluating the impact of intellectual impairment on 1,500-meter racing is a pacing test, which was selected because the ability to plan and pace a 1,500-meter race run appropriately is likely to be adversely affected by intellectual impairment, and in this way the test selected adheres to the second principle. The currently applied pacing test requires the athlete to run 400 meters at a constant submaximal pace of 80% of personal best (PB). The athlete is guided through the first 200 meters by means of an auditory signal at 20, 40, 60, 80, 120, 160, and 200 meters, marked by cones. Also the coach is allowed to provide feedback during the first 200 meters. For the last 200 meters, the athlete should keep the same 80% PB pace without any feedback (see Figure 7.5). Preliminary results indicate that athletes with intellectual impairment need more feedback to reach the requested pace in the first 200 meters and significantly deviate from the target pace in the unguided 200 meters compared to able-bodied peers.

### Coach’s Corner

In the eligibility classification process of athletes with intellectual impairment, the role of the coach is essential. Coaches should familiarize themselves with the sport-specific testing procedures in order to ensure that their athletes understand the task at hand and perform to their full potential.

If the time taken to run 1,500 meters was used as the performance measure, it is highly likely that the
impact of intellectual impairment would be masked by the influence of aerobic power, which is highly predictive of 1,500-meter time, but is not classified and the test would not comply with Principle 3. The extent to which the proposed test complies with Principle 1 could be addressed by scientifically evaluating how much of the variance in 1,500-meter time is accounted for by the ability to pace a 1,500-meter run independently.

In Example 3, two sport-specific tests have been selected. More than one test is indicated when the sport includes more than one activity that will be predictive of overall performance. On a purely hypothetical level, it seems reasonable to suggest that performance in downhill skiing will be influenced by the ability of an athlete to make high-speed turns when required, and by the ability to ski as quickly as possible over an uneven surface. If true, both tests would conform to Principle 1. Also hypothetically, it is likely that an athlete with vision impairment would find both these tasks more difficult than a person without vision impairment. If true, the tests would also conform to Principle 2. In order to conform to Principle 3, higher-level skiing proficiency must be an inclusion criterion. Statistical procedures can then be used to determine whether the predictive validity of using both tests is greater than it is for either one of those tests alone. Example 4 provides an extension of the point illustrated by Example 3. It is possible that, in combination, the four tests given in Example 4 will have greater predictive validity than any one of the tests used individually. As the predictive validity of the sport-specific test battery increases, researchers can have greater confidence that they are truly quantifying the impact that target impairments have on overall sport performance.

**Coach’s Corner**

Coaches and athletes provide a critical perspective in expert consultation and meetings, providing authentic, grounded views about the feasibility, validity, and relevance of sport-specific tests.

The sports presented in Examples 1–4 have an important, advantageous feature in common: overall sports performance is measured with a single, ratio-scaled measure (either distance or time). The advantage is that the validity of a sports-specific measure of performance can be objectively evaluated (measured). To illustrate, the validity of each of the four swimming tests nominated in Example 4 could be evaluated by correlating each test outcome with swimming performance (time taken to swim two laps of a 50-meter pool), with the results indicating the magnitude of the correlation and whether it is statistically significant. In contrast, overall performance in wheelchair rugby is not captured by a single measure (ratio scaled or not), and this is the case in 15 of the 27 Paralympic sports. From the perspective of developing evidence-based systems of classification, this means that it is not easy to evaluate objectively the validity of a battery of sport-specific measures of performance in these sports. The use of rigorous qualitative methods, including the Delphi review method
and convening expert meetings (identified previously when describing QA1), can play an important role in establishing the validity of a sport-specific test battery in these sports.

Once they have selected tests conforming to the three principles, researchers must develop detailed protocols for each of the tests. The principles of measurement require that any test of body structures or functions has a single, highly standardized, reproducible protocol. This principle is captured in the Position Stand, which says that “it is critical that all athletes perform exactly the same, highly standardized activity (i.e., same equipment, positioning etc.).” The implication is that if during research athletes adopt their own individualized positioning, strapping, and other aids, each is effectively doing a different activity, limiting the ability of researchers to draw valid conclusions about how much impact different impairments have on sport performance.

The requirement for standardization can present a challenge, because athletes with a wide range of impairments, from mild to severe, often participate in the same sport and must therefore do the same sports-specific tests of performance. At present there is no fail-safe formula for developing a test that can be done by all athletes who are eligible for a sport, but the following guidelines could be helpful.

**Develop the “least restrictive” protocol**

This can be done in two ways:

- Consider the full spectrum of athletes who participate in the sport and devise a protocol (including positioning and use of straps standard to the test) that can be completed by those with the most severe impairments. Piloting protocols with the help of volunteer athletes who have more severe impairments is enormously helpful in this regard.

- Conduct studies to evaluate which protocol will allow most people to perform at their best. For example, in Paralympic seated throwing events, a wide range of throwing frame configurations is permitted by the technical rules of the sport (International Paralympic Committee, 2014). In order to identify a suitable standardized sitting position, a recent study used a custom-built, adjustable throwing frame to identify the preferred seated throwing configurations of 47 non-disabled males (Tweedy et al., 2012). The results established seated throwing configurations preferred by non-disabled people and provided researchers wishing to evaluate the impact of impairment on seated throwing performance with an evidence-based guide for selecting a standardized throwing frame configuration.

**Develop protocols that incorporate legal technical aids and equipment**

Where possible, research test protocols should incorporate any technical aids and equipment that are legal in the sport. For example, if the technical rules of downhill skiing permit vision-impaired athletes to use tinted lenses or sunglasses to assist with vision during competition, then research should consider testing participants performing the sport-specific performance tests also using such aids. If a classification system is developed based on research evaluating the relationship between impairment and an activity in which athletes did not use available technical aids, then when such a system is implemented and athletes have access to the technical aids, some athletes may be able to reduce the activity limitation caused by their impairment significantly, providing them with an unfair competitive advantage over others in their class.

**Accurately record any individualization permitted in the protocol**

Sometimes, for practical reasons, testing protocols must permit athletes to use individualized positioning and technical aids. For example, wheelchair track athletes often have highly individualized wheelchairs and seating configurations that take into account their body dimensions, postural characteristics (e.g., scoliosis and contracture), comfort, and skin care. A recent study evaluated the impact of trunk strength on acceleration in wheelchair track racers (Vanlandewijck et al., 2011), in which performance measures were taken with the athlete in their own individualized chair because it was not possible to have one wheelchair configuration that accommodated all athletes. However, in reporting the results, the authors acknowledged that individualization was a limitation and identified and
described 14 areas of individualization, providing a basis for investigating any effects of individualized positioning.

**Quantify the effect of individualized positioning or technical aids on sports performance**

It is acknowledged that, while performance measurement for research purposes requires highly standardized protocols, sports rules generally permit some degree of individualization, permitting athletes to choose positioning that allows them to minimize the impact of their impairment on performance. Using within-group research designs, researchers can conduct studies that compare sports performance under standardized research conditions with performance under individualized, competitive conditions in order to evaluate whether individualization confers a performance advantage and, if so, its magnitude. Outcomes of such studies can provide an objective means of evaluating whether a standardized sports performance test provides a valid indication of sports performance under individualized, competitive conditions. It may also be possible to use the results to control for the impact of individualization statistically.

**Step 4: Assess the relative strength of association between valid measures of impairment and sport-specific measure(s) of sport performance**

To date, a small number of published studies have evaluated the relative strength of association between measures of impairment and sport-specific measures of performance in athletes with disabilities (Vanlandewijck et al., 2011; de Groot et al., 2012; Connick et al., 2015). These studies can provide researchers with a practical illustration of the research design required to execute Step 4. For example, in the study by Connick et al. (2015), 13 runners from classes T35–T38 (for athletes with hypertonia, ataxia, or athetosis) completed a 60-meter sprint and eight novel tests of lower-limb impairment, five lower-limb ranges of movement tests, and three lower-limb coordination tests. Each of the eight tests was completed separately on each leg (the more affected and less affected), yielding a total of 16 measures. Five of these measures were significantly associated with 60-meter sprint time, indicating that they were important determinants of sprint performance (Connick et al., 2015).

In the short term, tests of impairment that have a strong and statistically significant association with sport-specific measures of performance may be able to be directly incorporated into current classification systems and strengthen the evidence on which classification decisions are made. A range of practical considerations will determine whether this is possible: the expense and international availability of equipment (currently, classification must be conducted at competition locations all around the world), equipment size and transportability, equipment maintenance and calibration, and implications for classifier training. In instances where researchers have investigated the relationship between impairment and performance using highly sophisticated expensive or immobile instruments to measure impairment, there will be a requirement for translational research to develop and validate more accessible and practical methods of assessment that can be readily incorporated into classification practice. It should also be noted that the incorporation of individual tests into current classification systems will not lead to an evidence-based system of classification. To achieve this, Step 5 is required.

Arguably, the most sophisticated method that can be employed in Step 4 is mathematical modeling, simulation, and optimization. It takes considerable time and expertise to develop high-quality mathematical models, but the trade-off is more dependable results. For example, a recently published pre-pilot study described how musculoskeletal inverse dynamics using the AnyBody Modeling System (AnyBody Technology A/S, Aalborg, Denmark) could be used to simulate how a lower-leg prosthesis may affect the muscular work required during cross-country skiing (Holmberg et al., 2012). Specifically, results indicated that when the cross-country skiing motion is executed without muscles in the right lower leg and foot, the total metabolic muscle work done for a given amount of external work is greater than when the muscles are present.
In relation to physical impairments, information from studies using biomechanical modeling have the potential to provide information that can enhance our understanding of how each of the eight impairment types has an impact on sport performance. However, its greatest potential is in relationship to the three impairments of structure: limb deficiency (i.e., amputation and dysmelia), leg length difference, and short stature. Each of these impairment types lends itself to mathematical simulation because the outcome measure is in centimeters (e.g., residual limb length, leg length, or standing height). This is a simple, one-dimensional, ratio-scaled measure, and makes the impairments comparatively easy to simulate. Furthermore, input measures to the model can be accurately acquired from athletes in a classification setting. As a result, it is possible that in the future, knowledge about the impairment–sport performance relationship resulting from biomechanical simulation of impairments in mathematical models may be translated into classification systems for these impairment types.

The principal focus of research efforts in the area of evidence-based classification must be on evaluating the strength of association between measures of impairment and sport-specific measures of performance. However, as data accrue and systems are developed, researchers will be able to enhance the validity of classification systems through the study of factors that may mediate the impairment–sport performance relationship resulting from biomechanical simulation of impairments in mathematical models may be translated into classification systems for these impairment types.

Congenital vs. acquired impairments

Anecdotally, athletes in some sports report that people who acquire the impairment later in their development might have an advantage or disadvantage when compared to athletes who have a congenital impairment. A recent Delphi review study conducted with experts in sports for athletes with vision impairment found this issue to be of particular concern to some stakeholders in the visual impairment sports community (Ravensberg et al., in review).

Based on current evidence, it is difficult to say with any great certainty whether a person competing on the basis of a vision impairment will be at a relative advantage or disadvantage as a result of the age at which they acquired that impairment. On the one hand, there is some reason to believe that an athlete with an impairment acquired later in life may have an advantage over an athlete with an identical impairment that was present from birth. For instance, vision is increasingly understood to have a very important role to play in the way in which motor skills are learned. A system of “mirror neuron brain cells” has been discovered that are activated both when someone performs an action, and when they observe another person performing a similar action (Rizzolatti and Craighero, 2004). This discovery is in alignment with the theory of “common coding,” which suggests that there is a strong link between perceptual representations (for what is seen and heard) and motor representations (for actions that are performed) in the brain (Prinz, 2014). Importantly, this means that when a movement is seen, the action system is primed to repeat it, and it is on this basis that many motor skills may be learned through imitating the actions of others. As a result, a congenital visual impairment will impair the ability of an individual to learn in this manner and therefore may introduce a significant barrier to motor skill acquisition. Consequently, in sports that require an athlete to learn complex movements (like swimming or judo), it might be an advantage to have learned the movement with the benefit of vision so that athletes have a visual model of the movement that they are trying to perform. This could mean that an athlete with a congenital impairment (who might not have a visual model) may be at a relative disadvantage in those sports.

However, there is also reason to believe that a person competing on the basis of an acquired impairment may be at a disadvantage in some sports when compared to a person competing with a congenital impairment. For example, an athlete with a congenital impairment will have had more opportunity to adapt to and become accustomed to the impairment. Further, an increasing understanding of the plasticity of the brain suggests that those with a congenital vision impairment may also have
experienced “sensory substitution,” where their sensitivity to other sensory information (e.g., hearing and touch) is enhanced to compensate for the loss of vision (Rauschecker, 1995). The area of the brain typically dedicated to vision is known to be recruited for the processing of other sensory information in the congenitally blind, and this may account at least in part for their increased sensitivity to other sensory information (Cohen et al., 1997). Accordingly, if this greater sensitivity to other sensory information is useful in the acquisition and/or performance of a motor skill, then this may afford a particular advantage to those with a congenital rather than acquired impairment. This is particularly relevant in a sport such as vision impaired shooting, where target guidance is performed with auditory assistance, and it could be that an athlete with a congenital impairment who may have a more refined auditory system is at a relative advantage when compared to a person with an impairment acquired later in life who has not altered their auditory ability.

Impact of training on measures of impairment

In developing measures of impairment, it is crucial to consider the training responsiveness of some eligible impairment types (i.e., range of movement, strength, and coordination). A feature of eligible impairment types is that they must be permanent (International Paralympic Committee, 2007). However, while people with incomplete spinal cord injury or spastic hypertonia will have permanently impaired muscle strength, the measured strength of affected muscle groups can be markedly reduced by chronic disuse or increased through resistance training (Damiano and Abel, 1998; Glinsky et al., 2007). It is vital that athletes who have positively influenced their impairment scores through effective training are not competitively disadvantaged by being placed into a class with athletes who have less severe impairments (Beckman and Tweedy, 2009; Tweedy and Vanlandewijck, 2011). This challenge can be managed in four ways.

The first way is to ensure that methods developed for assessing impairment are, as far as possible, resistant to the effects of sports training. For example, in the sport of athletics, many athletes use plyometric and power training drills to enhance performance. Therefore, if strength impairment were assessed using a plyometric or power measure, it is likely that a well-trained athlete would perform better than an untrained athlete of comparable impairment severity, creating the possibility that the well-trained athlete would be placed in a class for athletes with less severe impairments. Isometric strength is not usually used in training by athletes and evidence indicates that isometric measures do not respond to power-type training typically used for performance enhancement (Baker et al., 1994). This makes isometric strength testing a more suitable measure of strength impairment for the purposes of classification in Paralympic athletics.

The second method is to develop tests that will differentiate well-trained athletes from poorly trained athletes. Beckman and Tweedy (2009) have described a test battery that can be used for this purpose in the sport of track athletics. The tests outlined have the potential to be used to differentiate athletes who are well trained from those who are untrained, thereby minimizing the risk of unintentionally placing well-trained athletes at a competitive disadvantage. Similar studies in the other impairment groups and for other sports are also possible.

The third way is to conduct training studies in which measures of impairment are taken prior to the commencement of a training period, and again at the end of the training period so that changes in impairment scores can be obtained. The value of these studies would depend on the quality and length of the training period: a high-quality, periodized training intervention conducted over 12 months or more would provide the best indication of the extent to which the different measures of impairment respond to training. Outcomes would provide an indication of whether impairment scores change and, if they do, whether methods for factoring in the effect of training are required.

The final method is to compare generic and sport-specific activities, performance only on the latter being improved through training. This could be applied to the wheelchair athlete with athetosis (CP3 in CP-ISRA classification) whose coordination
would be better in the sagittal plane, the plane of wheelchair propulsion, compared to the non-trained frontal plane. This method is also used in the eligibility process of athletes with intellectual impairment. For example, to assess fluid intelligence in a generic way (fluid intelligence is defined as the ability to solve new problems, use logic in new situations, and identify patterns), the athlete will look at a matrix from which a section is missing and complete the matrix by pointing to one of five response options (see Figure 7.6A). It is clear that this task is distant from the sports environment and that the majority of athletes with intellectual impairment will underperform compared to able-bodied peers. However, years of experience playing basketball might allow a player with intellectual
impairment to recognize basketball-specific transition patterns and solve a series test (see Figure 7.6B), requiring the athlete to reorder four photographs in the sequence of action. In this way, by comparing generic and sport-specific activities, training impact can be understood.

**Step 5: Use outcomes from Step 4 to determine minimum impairment criteria, number of classes, and methods for allocating classes**

A genuinely evidence-based system of classification requires that methods for assessing each of the impairment types eligible for a particular sport or event have been developed (Step 3a) and that all tests have a known, quantified association with sport performance (Step 4). Step 5 is the final one, leading to a system of classification that has an evidence-based method for determining the minimum impairment criteria (MIC), the number of classes required, and the necessary method for allocating classes. Currently there is no Paralympic sport in a position to undertake Step 5, but the broad principles are outlined here for the sake of completion.

Conceptually, the aim of MIC is to ensure that all athletes competing in a sport have an impairment that is severe enough to adversely affect performance in that sport. However, as acknowledged in the Position Stand, achieving this aim is complex, because it is affected by sports culture and norms and more than one view may sometimes be considered valid. If the MIC is set too conservatively, then athletes who have impairments that are mild but still have a significant adverse impact on sports performance will be ruled ineligible. Conversely, if the MIC is not sufficiently conservative, then the qualitative and quantitative performance of athletes who meet the criteria may be indistinguishable from that of non-disabled athletes, calling into question the legitimacy of the least-impaired Paralympic classes. Consequently, the development of MIC should draw on scientific evidence generated in Step 4 that quantifies the extent of activity limitation caused by different impairment types, but should be complemented by consensus methods to ensure that the activity limitation experienced by athletes who meet the criteria reflects the views of key stakeholders in the sport – athletes, coaches, sports scientists, administrators, and classifiers.

A range of different statistical methods could be used to develop impairment-based methods of class allocation. For example, cluster analysis refers to a range of statistical procedures that are used to group objects according to their similarity (e.g., K-means). Eligible athletes would complete a test battery including measures of impairment, each with a known strength of association with sports performance. The K-means algorithm would be used to create clusters of people who had impairments that cause about the same amount of difficulty in sport. That algorithm would then be applied in classification.

It is important to note that while the statistical procedures outlined here are rather sophisticated and the procedural details might not be widely understood among Paralympic stakeholders (athletes, coaches, classifiers, administrators, and the general public), it will be critical that the outcomes make sense to all stakeholders. To ensure that this is the case, translational work should be conducted in which researchers work closely with the IPC and the relevant governing bodies of the sports to evaluate the acceptability of the methods proposed, the impact they will have on competition structure, and whether they are understood and supported by stakeholders.

**Conclusions**

The principal aim of this chapter is to provide an overview of the research required for the development of evidence-based systems of classification for the three main impairment groups in Paralympic sport: physical impairments, vision impairments, and intellectual impairments. The overview makes it very clear that there is an enormous amount of work to be done before evidence-based systems of classification are in place for all Paralympic sports. However, it is vital for the Paralympic Movement that the agenda keeps moving forward. Unless it
Research needs for the development of evidence-based systems of classification

does, it will not be possible to realize fully the vision of the Movement: to enable Paralympic athletes to achieve sporting excellence and inspire and excite the world. This is because the achievement of sporting excellence is an entirely relative exercise. Any sporting achievement is only great, only considered excellent, if it is better than everybody else's. If classes are not composed of athletes that have impairments that cause approximately the same amount of activity limitation, confidence in Paralympic achievement is eroded and the Paralympic vision cannot be realized.

Advances in medical treatment and assistive technology, which are developed with the best intentions and improve the lives of people with disabilities throughout the world, can pose a significant threat to the validity of classification if they are permitted in sports without considering how they will affect the relationship between impairment and sport performance. For example, it has recently been reported that electronic implants known as neuroprosthetics can be used by people with complete thoracic spinal cord injuries to stabilize the pelvis and trunk by using low levels of continuous electrical stimulation in a way that has a positive impact on the mechanics of manual wheelchair propulsion, reducing both perceived and physical measures of effort (Triolo et al., 2013). This is clearly a wonderful advance in rehabilitation. It might be tempting for administrators or technical officials in a sport for wheelchair users to permit athletes to use such devices and thereby enhance their performance. However, unless the introduction were to be preceded by a detailed consideration of how these neuroprosthetics might affect classification in the sport, it could lead to a wide array of unintended negative consequences, including, but not limited to, providing certain athletes with an unfair competitive advantage. Changes in technical rules, whether they relate to technique or aids and equipment, must only ever be introduced after the impact on classification has been fully considered.

As important as the achievement of a level playing field is, classification will always be a tool with limited resolution and precision. It is not possible to eliminate all the inequity that can arise as a result of hugely diverse impairment profiles in the Paralympic Movement. Classification is not, and never can be, an exact science. The mission of researchers in this field is to develop systems of classification that have a sound scientific basis, that achieve good face validity (i.e., acceptability for athletes and understanding among spectators and the general public), and that have limitations that are understood and accepted.

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References


Introduction

Technology is the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment. In a sporting context, technology is often used as a means for performance enhancement (Burkett et al., 2011). Technological advances and innovative practice to implement technology have been and continue to be a hallmark of sport and exercise science (Winter et al., 2007).

There were two revolutions in the world of modern sport as we know it today. The first is “moving into professionalism” in the late 1970s. This change was supported by the crowd and mainly by the marketing industry. The second revolution is a technological one, defined as “a dramatic change brought about relatively quickly by the introduction of some new technology” (Bostrom, 2007). We are all part of this revolution, it affects every sport, and new sports have been born thanks to novel technologies.

Technology in Paralympic sports

The relationship between Paralympic sports and technology is as old as the Paralympic Movement itself. The focus has often been on the equipment that athletes use to compete or train with; however, advances in technology are also changing the face of these sports completely.

There are many different applications of technology in Paralympic sports. In fact, each chapter in this book has some technology-related aspects (e.g., technology used to analyze specific biomechanical aspects of movement in Chapter 2, technology used for measuring metabolic responses to sport-specific activities in Chapter 3, etc.).

The most basic application of technology in sport is technology that makes sport possible, such as equipment or surfaces. Without it there is no play (e.g., goalball, archery, sailing, or track and field equipment). In the Summer Paralympic Games many sports can exist thanks to wheelchairs, and the Winter Paralympic Games can only take place thanks to adapted equipment such as ice hockey sledges and sit skis. Adaptive equipment such as customized wheelchairs, specific to the individual athlete and the demands of the sport, and lightweight, energy-efficient prosthetics are just two examples of technological developments that have changed the image of Paralympic competition recently. The latest developments in technology have enabled increased participation in sports at the grassroots level for people with impairments, while at the elite Paralympic level they have also contributed to vast improvements in performance.
Another well-appreciated application of technology in sport is that aiming to reduce the risk of injuries through equipment configuration and optimization of the athlete–equipment interface (see Chapter 4 in this book).

With the aim to go higher, faster, and bring home a gold medal, athletes found that standard devices can actually detract from their performance. To satisfy athletes’ demands, new developments brought radical equipment designs such as the flex-foot or high-tech technology in cycling and racing wheelchairs, which have changed their sports dramatically (Burkett et al., 2011). Perhaps the most famous sportswear debate relates to the Speedo Lazer (LZR) swimsuit. At the 2008 Beijing Games, 94% of all swimming races were won by swimmers wearing this swimsuit. A total of 108 world records were broken, mostly by swimmers wearing the new controversial suits (Burkett, 2010). A more recent example is from the Sochi Winter Games, where the US, Canadian, and Russian freestyle ski teams all had their uniforms made by the Columbia Sportswear Company. Amber Lee, a contributor to Tech Reviews, explains that “Columbia employed a new zipper design to cut down on weight, and also a snow camouflage pattern that helps mask body movement” (http://breakingmuscle.com/sports/technology-doping-in-the-olympics-cheating-or-progress).

While some advanced technology is beneficial to all, such as technology in broadcast services that improves athlete–audience interaction and that assisting in providing more accurate scores (e.g., photo-finish, playback, or the Hawk-Eye ball-tracking system), other technology is the kind that only money can buy and leads to disparities between affluent countries and developing countries. An example of that is a simple fact: track athletes from Africa dominate Olympic races, but they lack the means needed for the expensive high-tech Paralympic track sports.

Unfortunately, this situation of inequitable access to technology is not going to change. On the contrary: as technology and assistive devices continue to advance, the gap between the participation and performance of developed and developing countries is likely to continue. Coaches and athletes keep pursuing effective training methods, the finest equipment, sophisticated sporting machinery, and even doping, in order to improve sports performance and gain a competitive advantage. Technology plays a significant role in achieving that competitive advantage: “Technology doping is the practice of gaining a competitive advantage using sports equipment. It’s also called sports engineering, which sounds much more forgiving” (Miah, 2005). Dr. David James, a sport engineer from Sheffield Hallam University’s Centre for Sports Engineering Research, perfectly expresses how technology in the Paralympic movement can outweigh the impact of human performance: “The Paralympics is wedded to science and technology. In the Paralympics charter, science is a huge part of it. It’s all about enhancement; it’s all about making people better. We use technologies from car design, Formula One, aerospace. Each Paralympics, you will see an advance on the technologies being used” (quoted in Wrenn, 2012).

Since technology has become a very dominant factor in the Paralympic movement, the International Paralympic Committee (IPC) in 2011 felt the need to publish a policy statement on sport equipment (Section 2, Chapter 3.10). This policy recognizes the important role that sport equipment plays in Paralympic sport and promotes its use during IPC-sanctioned events as long as four fundamental principles are respected:

- **Safety** – all equipment in use must protect the health and safety of the user, other competitors, officials, spectators, and may not cause damage to the environment.
- **Fairness** – equipment needs to be regulated in sports rules in sufficient detail.
- **Universality** – the cost and large-scale availability of equipment should be considered to guarantee access to a sufficiently large number of athletes in the sport.
- **Physical prowess** – human performance is the critical endeavor to the sport performance, not the impact of technology and equipment.

The last application of technology in sport to be addressed here is technology applied for efficient training. Undoubtedly, this application is most relevant to coaches and athletes. In recent years, huge developments have taken place with regard to the technology that has been used to analyze
performance and feedback information to athletes and coaches. This is referred to as performance analysis and is the primary focus of this chapter. The aim of the next section is to inform and inspire Paralympic coaches to improve their coaching skills and strategies through the integration of novel and effective performance-analysis technologies into their regular training routine.

As a consequence of advances in technology, systems have been constructed to provide relevant sports-specific feedback to athletes during and shortly after training and competition about different aspects of their performance. Such feedback systems are primarily designed to assist athletes and to monitor their training for the purpose of achieving improved performance. Feedback is generated about the major determinants of sport performance, such as biomechanical analysis of the throws of the shot putter, individualized time–motion analysis of wheelchair rugby players, mechanical efficiency measurements in cyclists, and so on.

In the rest of this chapter, different technologies used to provide feedback to athletes and coaches are described. As technology changes rapidly, the focus is on developing new techniques and methods rather than on recommending specific devices.

_**Performance analysis**_

Performance analysis is the provision of objective and subjective feedback to performers trying to achieve a positive change in performance. Essentially, it is about informing the athlete what actually happened as opposed to what they perceived to be happening. According to Hughes and Franks (2008), athletes and coaches are only capable of accurately recalling less than 50% of performance. Therefore, in performance analysis it is essential to register the activity aiming to analyze the determinants of performance in a qualitative as well as quantitative manner.

Coaches and sports scientists generally use performance analysis to evaluate four major performance determinants: the physical, psychological, technical, and cognitive demands of the sport. For the psychological determinant of performance, the reader is referred to Chapter 5.

There are a variety of performance-analysis techniques available and the approach used depends largely on the type of analysis performed and/or the environment in which the performance takes place. The types of performance-analysis techniques vary from tactical and technical analyses to physical analyses. Tactical analyses typically provide a qualitative breakdown of skills and a summary of performance outcomes (i.e., positioning of defense, distribution of shots, etc.), which are usually achieved by video analysis. Technical analyses also focus heavily on the use of video and can either be statistical in nature, whereby information is gathered surrounding the proficiency of certain skills (e.g., shots on target, passing accuracy, possession, etc.), or biomechanical, whereby a qualitative or quantitative analysis of a performer’s technique can be made. Finally, physical analyses provide a quantitative insight into the external (e.g., distance covered, speeds reached, work–rest ratios, etc.) and internal (e.g., heart-rate monitoring, blood lactate responses, etc.) demands of training or competing in various sports. These analyses can also take place in either a competition or training environment, which is where the majority of analyses are conducted. However, certain physical analyses of performance, such as biomechanical or physiological analyses, can be extended to the laboratory environment to derive further detailed information about performance.

The type of data collection and analysis selected can also have an impact on the time it takes to provide information back to the athletes and coaches. Timing of feedback is critical, particularly for elite sports. In order for coaches and athletes to be able to make the most of the information presented, it needs to be fed back within a fairly short timeframe, so that the performance analyzed is still relatively fresh in the performer’s mind. Certain technology used for tactical and technical analyses (e.g., video analysis for statistical or qualitative feedback about performance) can achieve this. Some laboratory-based measures of performance can be slightly more time consuming, which can severely delay the feedback process. However, the type of measurement and the environment used for testing are largely dependent on the urgency with which the data are required.
Coach's Corner

Jonathan Coggan, a wheelchair rugby player from Great Britain, shares his perspective about the advantage of using video analysis as a feedback tool:

Video analysis in particular has been invaluable throughout my career. It has enabled me to see what I have done right and what I could do better during games and also gives me an insight into what our opponents can and cannot do. As players, we all have our opinions on what we think has happened, but video analysis provides facts about what has actually happened and has allowed me to improve aspects of my game.

The technology currently used for performance analysis has progressed dramatically over the years, from relatively simplistic and inexpensive video analysis to complex, state-of-the-art tracking technology to facilitate the quality of performance analysis provided to athletes and coaches. Innovations to software and practice have also both helped improve the quality of analysis and feedback that can be derived from simplistic measures of analysis to make performance analysis more attainable. The next section of this chapter explores some of the existing technologies used to analyze and feedback aspects of tactical, technical, and physical performance and demonstrates how these technologies have progressed.

Video analysis

Video is a technology that is very common in the sports world. Although video technology originated in the 1950s, its use in coaching is an innovation less than three decades old. Video can be used to gather information about various tactical and technical aspects of performance during both competition and training (Katz et al., 2008).

Standard video analysis

Standard video cameras (see Figure 8.1) use 25 frames per second (30 frames per second in North America) and are the most commonly used piece of video technology across the majority of sports. The popularity of video analysis is likely to be associated with its relatively low cost in combination with being very easy to operate and flexible to use in a number of environments. It has a number of uses across a wide range of sporting activities that vary in complexity. Perhaps the most simplistic application of video analysis is to gather qualitative information about tactical aspects of performance. This can be particularly effective in team sports, whereby coaches and athletes can observe tactical patterns of play of themselves or opponents during competition. It can also be used to observe specific performances or skill executions in a training environment. The benefit of using video analysis...
for qualitative purposes is that no further analysis is required on the recording, meaning that feedback can be delivered as soon after the performance as possible. Since there are no delays in providing feedback, this type of information can be particularly effective, providing a visual representation of the performance at a time when internal sensory information can still be associated with the motor execution of the task (Liebermann et al., 2002).

Standard-speed video analysis can also be used to compile vital quantitative technical data about a team or individual's performance by implementing simple notational analysis techniques. This type of task requires the coach or operator to "code" certain movements or patterns of play during a performance. This coding can either be conducted “live” during a performance using certain specialized software such as Sportscode (Sportstec, Warriewood, NSW, Australia) or Dartfish (Fribourg, Switzerland) or post-performance when the video can be reviewed for in-depth analysis. Live coding allows the coach to receive feedback during the event to consider immediate adjustments to play, whereas post-analysis allows for more detailed considerations for future planning.

Typically, notational analyses can be used to provide statistical information about a performance such as the number of successful passes, and indicators of shooting accuracy in a sport such as basketball. The addition of simple spatial calibrations within the field of view can also enable quantitative data to be obtained about a performer's technique. In throwing events, information relating to the angle and height of ball release can be quantified; however, speed of hand release would require a higher sampling frequency. Similarly, for an event such as the long jump or triple jump, the cadence and stride length of an athlete's approach can be calculated to present vital performance feedback to athletes and coaches, with the intention of improving future performances. Again, the use and development of specialized software have improved the way in which this information can be presented to coaches and athletes. Multiple videos of the athlete performing the same task give the opportunity for pre- and post-feedback comparisons of performance. Alternatively, images of one performance can be superimposed/overlaid on another performance to help make comparisons between performances at pre-determined events (e.g., point of release during the shot put). This can allow athletes and coaches to identify key differences in technique between successful and less successful performances.

**High-speed video analysis**

In order to obtain a more detailed analysis of performers' technical skills than is attainable by standard-speed video analysis, high-speed video analysis is being used more frequently. High-speed cameras capture more frames per second than standard-speed cameras, frequently in excess of 50 frames per second and, depending on the speed of the performance being captured, possibly extending to over 1,000 frames per second. This enables coaches and athletes to view their performances in more detail, which can be highly useful for identifying and correcting an athlete's technique. The use of multiple high-speed cameras can also create a three-dimensional (3D) analysis of a performer's technique. This type of analysis frequently occurs in a laboratory-based environment and through the use of complex biomechanical techniques, such as modeling, simulation, and inverse dynamics, aspects of technique can be optimized. However, it must be noted that this type of analysis is incredibly time consuming owing to its complexity, and thus does not always transfer itself favorably to athletes and coaches.

**Coach's Corner**

Coaches should consider high-speed video cameras, because they make it possible to see each individual frame of the performance, especially if the action occurs at faster than 25 frames per second. From a didactic perspective, coaches should teach athletes how to use the video analysis tools so that they can join in the assessment of their own performance analysis.

**Video-based tracking systems**

The previous sections on standard and high-speed video analysis have demonstrated how coaches and athletes can obtain valuable information about the
tactical and technical aspects of performance. However, the more recent emergence of automated video-based tracking systems has enabled athletes and coaches to extract more information about the physical aspects of performance, particularly in team sports. Multi-camera systems with customized software (e.g., Prozone) can be housed permanently within venues and can automatically track players’ movements during competition, with limited manual tracking required. In addition to the tactical and technical (statistical) information that these systems produce, various physical parameters relating to the external load of the performance are also output, including distance covered, speeds reached, and the times and distances covered in various speed zones. This type of information provides coaches with an awareness of the physical demands of the sport and how it may differ between players in different positional roles within a team.

Unfortunately, such systems are extremely expensive. As such, translation of automated video tracking to Paralympic team sports has rarely been possible, with only one research article conducted to date (Sarro et al., 2010). The study by Sarro et al. (2010) noted problems with automatically tracking players in an indoor environment with multiple video cameras due to the reflections from the sports hall's floor surface. This meant that a substantial percentage of the tracking had to be done manually, which is an extremely time-consuming process and as a result severely delays the feedback of information to athletes and coaches. This type of analysis therefore lends itself slightly better to research applications than to applied sport science settings.

In an elite sporting environment, information about external load is required on an almost daily basis to provide coaches with evidence-based information about the content of the training that they have been prescribing their athletes. By monitoring externally on a daily basis throughout a season, coaches and sport scientists may also identify when an athlete might be at a greater risk of injury. Any sudden increase in an athlete's training load can often be a sign of overtraining or overreaching, which clearly needs to be avoided. Monitoring external load regularly enables coaches to be more proactive about preventing injury risk.

**Virtual reality**

Virtual reality (VR) environments enable the user actively to participate and navigate in virtual events or worlds that monitor movement and provide immediate feedback while being highly engaging. Well-designed VR environments in sport involve realistic simulations of real or imagined activities that can be experienced in 3D video with surround sound, and offer verbal, visual, and tactile feedback (Katz et al., 2006). Of all the technologies available for measuring and improving performance, VR environments tend to be the most expensive to build, are complex to use, and are the least approachable by coaches, and therefore in the field of sport are mostly used by sport scientists (Katz et al., 2008). However, the availability of new tools such as Microsoft Kinect has enabled the development of inexpensive virtual environments in a variety of areas, including physical rehabilitation (Lozano-Quilis et al., 2014). These same environments could be used to provide feedback and enhance performance for Paralympic athletes.

In addition, Carling and colleagues (2009) suggest that VR simulators could be used to evaluate and correct skill proficiency such as striking a ball properly or the development of tactical decision-making techniques. Combining VR environments with tools such as biosensors that are relatively unobtrusive and would allow for adaptations for physical challenges would be an excellent means of measuring movement and monitoring biological activity. The system could then provide sophisticated feedback to the participant. Recent research by Vignais et al. (2015) suggests that virtual environments are very effective at improving the performance of goalkeepers. Such systems could be adapted for Paralympic athletes as well.

Virtual reality environments can also be used for virtual rehabilitation. Virtual rehabilitation involves the use of VR environments for patient populations to provide therapy. Well-designed virtual rehabilitation systems allow for customized parameters for each patient. Given the unique needs of Paralympic athletes, virtual rehabilitation and virtual training to reduce injury have great potential.
Coach's Corner

Virtual rehabilitation has great potential to help athletes recover from injury and many of the existing systems are customizable.

Wearable technology

Over recent years, large strides have been made with regard to the amount of wearable technology available within a sporting environment. Wearable technology has played an important role in furthering knowledge about the physical demands of sports competition and training, which was highlighted as an issue in the previous section. Wearable technology, as the name suggests, is technology that athletes can wear to monitor their activity and their responses to a dose of exercise. A key requirement of wearable technology to be used in a sporting environment is that it can be worn by athletes without influencing their performance.

Coach's Corner

Handcyclist Kobi Leon from Israel, silver medalist at the 2012 London Paralympic Games, shares his perspective on the use of a GPS tracker in his training:

Training with the activity tracker significantly changed my training style and raised the quality of my training as well. Since I receive feedback throughout the training about my ability, I am not influenced by external distractions such as wind and rain as it was before. I do not have to look at a lot of measures – actually I have one number that shows me everything about my ability (I almost totally stopped looking at my heart rate for example). In addition, I don’t rely on my feelings or subjective perspectives. Also, for my coach, it helps a lot. It is much easier for him to analyze the training after it’s done and to plan the next workout accordingly – even if he was not there with me, he could still follow exactly what I did minute after minute.

Global positioning systems

Global positioning systems (GPS) are used extensively by a variety of individual and team sports on a daily basis to monitor the external workload of athletes. They are incredibly easy to use, since no time-consuming calibration is required, and are relatively non-invasive, since athletes only have to wear a small unit that sits between the shoulder blades and is housed within a GPS vest. In swimming, the GPS tracker is attached to the back of the head by clipping it to the swim goggle straps. The units simply communicate with satellites to produce real-time coordinates of the athlete’s position. Data can then be analyzed to acquire similar physical information about performance to that described in the previous section (distances, speed, etc.).

Although GPS are very practical to use within a sports environment, they have also progressed from units capable of recording at only 1 Hz to 15 Hz, which has led to much more accurate and reliable data being reported to coaches about their athletes’ performance. GPS provide coaches with information about the volume (distances, time) and intensity (speeds, time in speed zones) of the external work performed during a match or training session (Cummins et al., 2013). This technology is often combined with heart-rate monitors, another form of wearable technology that can determine the internal responses of each athlete to a dose of exercise.

While GPS tracking is a practical and reliable method for analyzing the physical aspects of performance, it is still relatively expensive. However, the major limitation with GPS tracking is that because of its reliance on satellite signals, it only works outdoors, which means that it is not available to indoor team sports such as wheelchair basketball or wheelchair rugby.

Data loggers

Data loggers are data-acquisition devices that take readings at a pre-set interval and store them in the internal memory for download later. This is a form of wearable technology that has been introduced in an attempt to acquire information about the physical aspects of sporting performance. The benefit of data loggers is that unlike GPS they are not restricted by the type of environment they are in and therefore can be utilized indoors. Unfortunately, as their name suggests, these devices just “log” data and nothing is collected in real time, which means that post-event data processing
is required of the information relating to the players’ external load, which can delay feedback and limit the appeal of data loggers to both coaches and athletes.

Miniaturized data loggers (MDL; Human Engineering Research Laboratories, Pittsburgh, USA) are specifically for use on wheelchairs. Developed originally to quantify the volume and intensity of activity during daily living tasks (Tolerico et al., 2007), MDL have recently been employed during wheelchair sports (Sporner et al., 2009; Sindall et al., 2013). They are small, lightweight devices that can be attached near the axle of sports wheels (see Figure 8.2). An MDL contains three magnetic reed switches and is activated by wheel rotation (every time the wheel rotates and one of the reed switches passes by a magnetic pendulum, a timestamp is recorded to the 0.10 second). Three reed switch activations in succession equates to one wheel rotation. Subsequently, using the dimensions of each individual’s wheel, the MDL can be used to calculate parameters associated with the volume of activity performed:

\[
\text{Distance (m)} = \text{number of reed activations} \times \frac{1}{3} \text{wheel circumference (m)}
\]

\[
\text{Mean speed (m⋅s}^{-1}) = \frac{\text{distance covered (m)}}{\text{playing time (s)}}
\]

The weight of wearable technology is vital so that athletes are not aware of the device and it will not inhibit their performance. An MDL weighs approximately 96 g and is easy to attach to a wide range of wheels, meaning that athletes can be monitored in their own wheelchairs, which is also important. MDL are also equipped with long-life lithium batteries, which have the potential to collect and store data continuously over a period of three months (Tolerico et al., 2007). This could have beneficial practical implications for a sports scientist, since the MDL could be attached to an athlete’s sports wheelchair to collect vital information about the distances covered and the speeds reached during every training session over an extended period. Practitioners could then simply review each athlete’s performance and then modify future training phases accordingly, with minimal input required at each training session, which is not always feasible without the technology.

Despite the practical advantages that have been associated with MDL, there are a number of drawbacks that have ultimately limited its use for sporting applications. The major drawbacks concern issues surrounding the accuracy and reliability of the devices at high speeds. Sindall et al. (2013) showed that MDL provided an accurate and reliable representation of the distances covered at low speeds (<2.5 m⋅s\(^{-1}\)). However, at higher speeds (>2.5 m⋅s\(^{-1}\)) MDL were shown to be far less reliable. Given that wheelchair court sports are thought to be dominated by aerobic activity interspersed with bursts of high-speed activity (Goosey-Tolfrey et al., 2006), it is vital that any device used to quantify the demands of these sports must be capable of operating reliably at high speeds.

The way in which MDL operate also means that they are not capable of providing an accurate and reliable measure of peak speed, which is another key performance indicator that needs to be monitored in wheelchair court sports.
Since MDL cannot report speeds instantaneously, as they are dependent on reed switch activations, peak speeds have previously been reported as “average speeds” over either a 1- or 5-second interval. Although Mason et al. (2014) reported that 1-second analysis intervals provided a more accurate representation of peak speeds during wheelchair rugby than 5-second intervals, MDL still underestimated athletes’ true peak speed. In practical terms this could have a severely negative influence on the training prescribed to athletes, since relative speed zones determined from peak speeds are emerging as a popular method for monitoring an athlete’s performance specific to each individual during team sports (Ven-ter et al., 2011; Cahill et al., 2013). Any inaccuracies in the detection of peak speed can then become exacerbated when attempting to quantify activity in a range of speed zones related to this parameter.

Wearable technology clothing

Another area that has great potential for performance analysis is wearable technology clothing. The Reebok Checklight, developed by MC10 Corporation (Lexington, MA, USA) for Reebok (http://www.mc10inc.com/consumer-products/sports/checklight), is a wearable skullcap that provides consistent, reliable action impact data using sensors that are directly coupled to the head to reflect direct accelerations that the head experiences. It is easy to use and comfortable to wear and can be worn with or without a helmet and in multiple activities. The skullcap logs the total number of impacts recorded and the magnitude of the impact in real time.

The Hexoskin (http://www.hexoskin.com; Carré Technologies Inc., Montreal, Canada) is one of a number of new biometric shirts that can monitor multiple variables such as heart rate, acceleration, breathing rate, activity intensity, and minute ventilation. These shirts are comfortable to wear and some of them can provide real-time data. Design modifications may be required for the unique needs of some Paralympic athletes, but the value of these new tools for providing important physiological and tracking data for athletes and coaches is amazing.

Instrumented sport equipment

One of the more exciting sports innovations is the use of instrumented equipment. A French tennis equipment maker, Babolat (Lyon, France), has developed a Pure Drive Tennis Racquet (http://www.babolat.com/product/tennis/racket/pure-drive++-102167) featuring built-in technology to monitor many aspects of play, including ball impact, power of swing, technique, and endurance. The system also records the number of backhands, forehands, smashes, and serves. For a coach, having that data on a tablet or smartphone is ideal for immediate feedback to the athlete.

Other notable products include an instrumented basketball created by Infomotion Sports Technology, Inc. (Dublin, OH, USA; http://www.94fifty.com/). The 94Fifty also uses a wifi connection between the ball and either a smartphone or tablet. It is easy to use – all you have to do is buy the ball and charger, download the app on your smart device (IOS or Android), activate the ball, and dribble four times to start. You can then capture the number of dribbles, dribble power, shot speed, and shot arc.

Another player in the instrumented equipment market is Adidas (Herzogenaurach, Germany) with its instrumented soccer ball (http://www.adidas.com/us/micoach-smart-ball/G83963.html). Like the 94Fifty basketball, the Adidas soccer ball has a sensor that measures kicking technique, with instant feedback on power, spin, strike, and trajectory.

Coach’s Corner

Coaches should be aware that these commercialized products are often not tested for psychometrics (i.e., accuracy, reliability, and validity). One option for coaches and athletes would be to collaborate with a sports scientist who can help evaluate the technology.

These instrumented tools are very useful for coaches as they provide instant feedback on performance based on how athletes handle the equipment. Furthermore, such resources are priced at a consumer level, so they are easily accessible.
Providing feedback in aiming sports

For aiming sports that require accuracy and precision, such as shooting or archery, vision is a primary feedback channel. Consequently, diverse technologies have been developed to improve skill learning and performance in these sports. In previous years, laser technology such as optoelectronic feedback systems was used, allowing performers to correct for deviations from the center of a target during aiming within very narrow error margins and at long distances. Researchers attached a laser device to the rifle in combination with a laser-sensitive grid to obtain visual information on the deviation from the center of a target in real time. A drawback of this method was the necessity of attaching the laser device to the rifle and the expense of calibrating the system (Heller et al., 2006). In recent years, the use of electronic trainers has reformed the training of shooting. By capturing valuable parameters such as the steadiness of a shooter’s hold, accuracy of aiming, and the timeliness of trigger release, these devices can offer remarkable insight into the strengths and weakness of a shooter’s position and technique. Popular trainers on the market include RIKA (Micheldorf, Germany), Noptel (Oulu, Finland), and the SCATT Training System (Moscow, Russia).

All existing electronic trainers operate on the same basic principle: an electronic optical sensor attached to the barrel of the weapon monitors the position of an infrared light source close to the target; the position of the light source within the sensor’s field of view determines the weapon’s point of aim at any given instant. The shooter aims at the electronic target, and a trace of the point of aim can then be followed on a “real-time” display screen. On activating the weapon trigger, the point of impact is displayed on the screen. All results of the training session are being recorded for further analysis. However, Tony Chow’s review of the SCATT MX-02 Electronic Trainer comments: “These products’ reliance on infrared results in a common weakness: the inability to use them in outdoor ranges for live fire training, as sunlight is full of infrared radiation that overwhelms the sensor” (www.accurateshooter.com/gear-reviews/review-scatt-mx-02-electronic-trainer).

Coach’s Corner

Shooter Doron Shaziri from Israel, six times medalist at the Paralympic Games, explains why he and his coach chose the SCATT training system:

With the SCATT, I cannot cheat. The tiniest mistake immediately appears. I get feedback about my stability, accuracy, the quality of my trigger pressing and more. What I really like is that it gives me a positive feedback allowing me to repeat the same routine in order to maintain my precise shooting.

The use of force platforms and contact mat systems as a feedback tool

The vertical jump is a fundamental skill in many sports. It is one of the most reliable and valid field tests for estimation of the explosive power of the lower limbs. Strength coaches are known to use jump tests for two reasons: to assess lower-body power performance improvements throughout a season; and for injury prevention related to fatigue, technique, and physiological state (Kenny et al., 2012). According to the literature, the most reliable and accurate technology to assess high jump is a sensitive force platform immobile system that requires athletes to be tested in the laboratory. For instrumented jump performance feedback in field testing, coaches use an electronic switch mat (ESM) because of the cost effectiveness and portability of such a device. The advantage of the ESM over traditional vertical jump and reach tests is that the ESM is generally more efficient and can therefore accommodate larger numbers of athletes in shorter periods of time (crucial for the conditioning trainer who occasionally has a limited timeframe with athletes or players). It also eliminates the need to measure the height of an athlete’s reach, is easy to transport, and requires very little storage space. Furthermore, the tester does not need to perform any calculations to derive the height of the jump (Klavora, 2000).
In the next sections, a few examples of applications of technologies in Paralympic performance analysis will be described. The first example is the role of the technology used in training environments and competition in wheelchair sports, based on the use of radio-frequency tracking systems.

**Application of innovative radio-frequency technology in wheelchair sports**

As mentioned earlier, technological limitations have previously prevented thorough physical analysis of performance in wheelchair court sports such as wheelchair basketball and wheelchair rugby. A tactical and technical analysis of these sports can be achieved using the same video analysis and statistical techniques employed in able-bodied sports. However, problems associated with accuracy and reliability have limited the use of MDL, whereas time-consuming analysis has prevented automated video-based tracking systems from being employed on a daily basis within these sports. Consequently, coaches and trainers within wheelchair court sports have not been able to quantify and monitor the external load that is placed on their athletes, either during competition or through the training programs that they have been prescribed. A detailed analysis of performance during competition enables coaches to understand more about the demands of the sport and those specific to each athlete. From a practical perspective, this information can be used to implement more individual training strategies tailored to the needs of each athlete. This type of approach not only promotes opportunities for performance optimization, it can also play an important role in minimizing injury risk.

As is often the case in Paralympic sports, in order to obtain the same information about performance with which professional, able-bodied sports are familiar, some form of innovation is required. This innovation can be either from the practitioners working with the sport or through innovations in technology. Recent technological innovations have seen the emergence of radio-frequency-based tracking systems such as the Local Position Measurement (LPM) system (Frencken *et al.*, 2010; Ogris *et al.*, 2012) and the Wireless Ad-hoc System for Positioning (WASP), both currently available and used in able-bodied team sports. Radio-frequency-based systems collect data in a manner similar to GPS, yet more importantly in an indoor environment.

Recently, a radio frequency-based system, referred to as the Indoor Tracking System (ITS), has been developed and validated specifically for use in wheelchair team sports (Rhodes *et al.*, 2014). The ITS is a real-time location system that comprises six sensors, which communicate wirelessly with lightweight tags worn by the athletes, either in a GPS vest or attached near the footplate of the athlete’s wheelchair (see Figure 8.3). The sensors detect ultra-wideband (UWB) radio signals sent from the tag, which can be used to provide the positional coordinates of a tag in three dimensions. Operating at a sampling frequency of 8 Hz, the ITS has been shown to provide extremely valid and reliable measures of distance and speed during movements specific to wheelchair court sports (Rhodes *et al.*, 2014). Relative errors in distance covered and mean speed were low (1%), yet importantly errors in peak speed detection never exceeded 2%, implying that the device was sufficiently accurate and reliable for use with elite sports.

The advantage of the ITS is not solely due to its accuracy, but also to the practical benefits associated with the device. It is essentially wearable technology, as athletes are required to wear a lightweight tag to track their movements on court; the tags weigh only 25 g and consequently do not have an impact on an athlete’s performance. The set-up of the system is extremely flexible, since the sensors can be fixed to the venue itself or elevated using tripods (see Figure 8.4), meaning that it can be used at a variety of locations. However, the main practical advantage of the ITS is that it can turn around meaningful feedback about performance...
moments after the competition or training session has been completed. Owing to customized software, information can be output in a user-friendly format to athletes and coaches instantly after a session. As demonstrated in Figure 8.5, valuable tactical information can be provided about performance through the use of a heat map synchronized with real-time video imaging. More importantly, it can provide vital information that has not previously been available about the volume and intensity of the work performed by each athlete.

The ITS has been used very recently during elite-level wheelchair rugby competitions (Rhodes et al., 2014, 2015). Valuable information has been derived from these scientific investigations, which enables a greater understanding of the sport. With respect to player classification, it was revealed that indicators of exercise volume (distance covered and average speed) increased with classification and that players from higher classifications achieved greater peak speeds than players from lower classifications, as would be expected (Rhodes et al., 2014).

Figure 8.3 Tags to track performance using the Indoor Tracking System (ITS) and where they can be located on the athlete.

Figure 8.4 How the Indoor Tracking System (ITS) can be set up and the location of sensors around the court.
Interestingly, while low-point players (<2.0) could not reach the same peak speeds as high-point players (≥ 2.0), they were shown to perform a greater number of high-intensity activities, defined as activity spent in a speed zone above 80% of an athlete’s peak speed, than did high-point players. This demonstrates the subtle differences in the demands of wheelchair rugby that exist between low-point and high-point players. However, the most valuable way in which the information can be used is to compare an individual’s data longitudinally. Figure 8.5 demonstrates the external load of a wheelchair rugby player during one quarter. Variables relating to volume and intensity of exercise can be compared throughout the course of a whole game to see whether there are any indicators of performance drop-off, which may indicate fatigue and hence an area of weakness for coaches to work on with specific athletes. The data can also be used to compare activity profiles over longer periods during competition, so that coaches can become more aware of the effectiveness of any training interventions that they have been performing. If a specific goal for an athlete was to improve their top-end speed or their fitness, the ITS can provide a simple answer to these questions in the most sports-specific environment possible, by identifying whether peak speeds have increased or greater distances are now able to be covered.

Figure 8.6 illustrates the physical data from the ITS of two wheelchair rugby players during competition. You can see how Player 1 demonstrates a more significant drop-off in both distance covered

Figure 8.5 A typical output produced by the Indoor Tracking System (ITS) detailing some of the physical aspects of performance.
Figure 8.6 An example of a match report produced by the Indoor Tracking System (ITS) detailing the different strengths and weaknesses of two wheelchair rugby players of similar classification.
and time spent performing high-intensity activities (> 75% peak speed) between the first and second halves of matches, which may be indicative of fatigue. Therefore aerobic and speed endurance training may be a necessary training prescription for this individual. Player 2 does not demonstrate such a drop in performance between halves, but the maximum speed that this individual is capable of achieving is markedly lower than for Player 1, who is of a similar classification. Therefore, speed training as opposed to fitness-based training may be a greater priority for this particular individual. In this way, simple evidence-based information from the competition environment highlights the strengths and weaknesses of individual athletes, and this information can then be used to make training more specific to the individual requirements of each athlete during competition.

Information derived from the competition environment is extremely important, allowing coaches and athletes to analyze the demands of the sport. However, it is meaningless unless this information is applied to the training environment. The training environment is where sport scientists can have a positive influence on the athlete’s performance, and information from the ITS during competition provides valuable assistance here. As noted, subtle differences in the volume and intensity of activity exist between classification groups during wheelchair rugby. This type of information can be utilized for planning individualized training sessions that are more specific to the demands of each player. This is vital information for sport scientists and coaches, since “generic” training programs have long been adopted in wheelchair team sports. Athletes have been required to perform similar volumes of exercise at similar intensities, regardless of classification, because a detailed understanding of how their physical demands differ has been missing. This type of approach is less than optimal, as it does not provide the appropriate training load to maximize the performance of all athletes. Just as importantly, the training volume could be excessive for certain athletes, placing them at unnecessary risk of injury. The ITS can also help sport scientists and coaches employ more evidence-based practice in the training environment.

In order to optimize physical performance and further improve the specificity of the exercise prescribed to each athlete, activity profiles should be monitored during typical training sessions. This has yet to be explored in the scientific literature from a wheelchair sports perspective. Nevertheless, it is imperative to determine how the demands of training currently compare to those of competition for individual players. This will allow sport scientists and coaches to pinpoint further what aspects of training need to be adapted for certain players to represent the demands of competition more accurately.

On-court training sessions for wheelchair team sports comprise a combination of skill-based, conditioning-based, game-related, and game-simulation drills. By using technology such as the ITS during training sessions, coaches can have a better appreciation of the physical demands of each of the different types of drills. Such information can assist greatly with the planning and design of training programs that can be modified depending on the training phase. Training periodization guidelines for team sports generally advise that high volumes of activity at relatively low intensities are performed during pre-season, which progress toward lower volumes and increased intensities as competitions approach, so that athletes are physically peaking at the right time of the season. Evidence-based data about the volume and intensity of each training session can inform coaches whether the exercise they are prescribing is correct for the given time of the season.

Although recent innovations in technology have enabled accurate information to be acquired about physical performance during wheelchair team sports in a practical and efficient manner, this information is still in its relative infancy in these sports and there is definitely room for growth and development. It is important to note that although great strides have been made to gather evidence-based data about the demands of competition and training, radio-frequency systems such as the ITS only provide information about the external load of the activity. While this is incredibly important, it is still necessary to understand the internal load placed on each athlete during the activity. Clearly, each athlete is unique and the internal responses of one
athlete may vary greatly to those of another athlete, even when the same external dose of training is prescribed. Therefore, in the future, an assessment of the internal responses of athletes should be considered alongside the external load of the activity, in order to optimize performance and minimize injury risk in wheelchair athletes.

**Biomechanical analysis of selected Paralympic athletes**

Performance analysis based on biomechanical measures describes the kinematics (i.e., motion characteristics) or kinetics (i.e., force characteristics) of movement behavior (Carling et al., 2009). Kinematic measures describe the location and movements of the limbs during skill execution. The most common technologies used to analyze movement kinematics are video, optoelectronic motion detection, or inertial sensor technology. Kinetics refers to the force produced during movement behavior and is commonly measured by means of a force platform, load cell, force transducer, and/or pressure mat. This section presents examples of the use of video analysis to improve elements within a few Paralympic individual sports (athletics, fencing, and boccia) based on single case studies.

**Coach’s Corner**

Some of the methods presented here can easily be used by coaches. Rough estimation of the stride length, rate, and speed can be made on a computer by utilizing the footage taken by a fixed-position consumer-grade video camera that is mounted on a tripod and with a designated length of calibration marks on the track.

**The sprinter**

The speed of running is a function of stride length and stride frequency. If a sprinter is running at a certain pace and wants to run a little faster, extra speed can be attained by taking longer strides or faster strides, or a combination of both. Kinematic analysis may help the sprinter determine the optimal stride length and stride frequency combination.

To find out the optimal stride length and stride frequency combination of a T36 Class 200-meter sprinter with cerebral palsy, the athlete was asked to increase stride frequency with a slight decrease in stride length. A digital video camera (Sony HDR-XR550E) sampling at 25 Hz was used to capture the sprinter’s running movement on the track at the Hong Kong Sports Institute during training in early 2012. The video footage was processed by Dartfish Team Pro 6.0 to quantify the sprinter’s movement data (see Figure 8.7). The athlete was asked to run a 100-meter distance; stride data were collected over a 60-meter section. In this case, a 3.5% decrease in stride length with an 8% increase in stride frequency resulted in an obvious increase in running speed. A bilateral stride length discrepancy of 4–7% was also found in this sprinter. This might be due to muscle strength differences between the left and right leg. Besides video-based motion analysis, timing gates or a laser speed gun can also be used to provide time and speed data. If force or pressure sensors are embedded in the starting blocks, the magnitude of the propulsive force of each leg can be registered. Such information will be helpful to prepare a strength training program.

**The foil fencer**

Fencing is a sport that includes both offensive and defensive actions, involving rapid extension and flexion of the trunk and arm. Hence, the analysis of trunk- and arm-movement data of the fencer can provide useful information for fencers in order to improve performance.

To profile and compare the trunk movement and attack area of two amputee Class A fencers, a 25 Hz digital video camera (Sony HDR-XR550E) was used to capture the trunk movement and attack patterns during a simulated competition held at the Hong Kong Sports Institute fencing hall in the middle of 2012. The video footage was processed by Dartfish Team Pro 6.0 to quantify the trunk movement (see Figure 8.8) and area of attack (see Figure 8.9) distribution of the fencers.

A basic fencing technique, also called a thrust, consists of extending the sword arm to declare an attack and attempting to land a touch on the opponent’s valid area. A trunk forward lean angle of
attack that is formed by a larger upper body, arm, and foil movement is the foundation of the attack movement (see Figure 8.8). On the other hand, a larger trunk backward lean angle of retraction produced a better defense, as it makes it more difficult for an opponent to produce an effective attack (Figure 8.8, bottom). With this video analysis, the characteristics of each fencer could be documented. One of the ways for a fencer to produce a larger trunk forward and backward lean angle of attack was by improving waist flexibility and strength.

In a simulated competition, 57% of a fencer’s total attacks were missed; that is, the foil did not make contact with the opponent’s body. The remaining attacks were effective (the color light of the scoring system was on) and non-effective attacks (the white light of the scoring system was on) with a ratio of 1:1. More than half of the fencer’s overall attacks (58%) were focused on the lower area (1 and 2) of his opponent (see Figure 8.9). Moreover, the fencer’s successful defensive rate is 69%. These results reflected the characteristics of this fencer’s individual skill. There will be a high degree of variation in performance for different levels of fencers. Comparison of data will only be made with opponents at a similar or the same level.

**The boccia athlete**

The stability of the wheelchair on the floor is especially important for a boccia athlete, who executes a powerful arm movement just before a throw (Mononen *et al.*, 2007). An unstable base greatly affects the athlete’s aiming accuracy. Although additional weight was already put on the wheelchair of the athlete in this case study to provide extra stability, to improve performance further a loading redistribution on the wheels was made by determining the reaction force on each wheel.

To assist a congenital locomotor dysfunction BC4 Class boccia athlete to improve the stability of his throw, a high-speed motion-analysis system and four force platforms were used to analyze the arm swing and wheelchair movement, and the reaction forces on each of the four wheels during the throw. A high-speed T40 Vicon motion-analysis system (Vicon Motion Systems Ltd., Oxford, UK) with a sampling rate of 200 Hz was synchronized with four Kistler force platforms (Kistler Group,
Winterthur, Switzerland), including two sets of model 9253A and two sets of model 9286BA, to collect the throwing movement data of a boccia athlete at the Hong Kong Sports Institute biomechanics laboratory in the middle of 2012. Vicon Nexus 1.6 software was used to collect and process the motion and force data (see Figure 8.10). The throwing technique and wheelchair motion analyses were performed at 9-meter touch ball throw and 5-meter push ball throw. The arm
movement range of two different throwing techniques and the forces exerted on wheels were measured and analyzed. A redistribution of metal dead weight on the frame below the seat of the wheelchair was proposed to increase the grasping power of the tires. A post-test with the same athlete was also conducted.

An increase in wheelchair stability was found after weight redistribution (Cognolato et al., 2014). The arm swing range in two different throwing techniques increased by 4% and 13%. Furthermore, the upper-body movement speed and ball speed also increased in the 5-meter push ball throw, which required greater arm swing power.
than the 9-meter touch ball throw; no speed increase was found in the 9-meter touch ball throw, which required controlled body movement. In conclusion, the increase in wheelchair stability might widen the upper body’s range of movement and increase throwing power without sacrificing accuracy.

**Implementation of technologies**

As demonstrated throughout this chapter, performance analysis and the use of innovative technology as part of a Paralympian’s training can have a huge impact on practice and help maximize performance. The implementation of a technology in Paralympic sport to assist with the assessment and improvement of performance requires careful planning, including convincing coaches and athletes of the value of the technology, funding for the purchase and maintenance of equipment, and training for coaches and athletes on how to use the innovation (Katz et al., 2009). The technology should be easy to use and maintain, and provide valuable and easily accessible information so as to encourage coaches and athletes to pursue innovation.

The willingness of a coach to participate in innovation depends on the background of the coach and the athlete, including technology experience, years of coaching experience, previous experience with change, belief in the potential effectiveness of the change, fear of change/level of risk taking, degree of involvement in decision making, authority to make decisions, support for innovation, and financial, technical, social, and emotional condition. Hutzler and Bergman (2011) studied mediating factors in pursuing a competitive Paralympic swimming career as well as the attributes of participation. One athlete said that the barrier to participation that he perceived during his career was due to his coach’s low professional efficacy. According to this athlete, the training contents and methods used in his group by some of the coaches were not up to date and were not at the level employed in competitive swimming clubs with able-bodied swimmer models. The willingness of a coach to use innovative performance-analysis tools can provide the coach and the athlete with valuable physiological, biomechanical, and technical parameters, and can also influence the psychological preparedness of the athlete.

**Extraction and analysis of data**

Once a technology has been implemented and data collected from athletes, the coach needs to analyze the performance. The performance criteria (e.g., time, score, speed) should be collected as often as practical for practices and competitions in which the athlete performs. The coach can then look at explanatory variables (e.g., video, force) to identify key differences between poor and good performances. Footage of the athlete in action should be replayed to the athlete, in conjunction with appropriate analysis and discussion.

**Coach’s Corner**

Collecting data is technically very easy – come up with a good plan for managing the data so that you can store it, recall it when needed, and use it for comparisons and decision making.

In some countries, mainly when working with top athletes, coaches and athletes have the advantage of a service provided by performance-analysis centers. Such centers provide expertise, technology-integration solutions, and performance-analysis services to sports organizations, athletes, and coaches. Their goal is to help improve athletes’ techniques/skills and team tactics/strategies through the use of measurement technologies. Interestingly, in the process of writing this chapter, the first author approached several experts from different performance-analysis centers in order to gain more insight into the novel technologies and techniques in current use. None of the centers’ leaders was willing to participate. This is understandable and perfectly described in the following quote from the English Institute of Sport: “Though to retain a competitive advantage over our competitors, much of the work done by the team does not enter the public domain. Innovation is a world where it pays to be secretive because any advances in technology
or technique could make the difference between ‘the best’ and ‘the rest.’” (http://www.eis2win.co.uk/pages/Research_Development.aspx).

**Coach’s Corner**

The ability to record and analyze an athlete’s sport-specific movement patterns is one of the most vital requirements of any coach. More “handy” tools are those used with smartphones and tablets. Apps such as Hudl Technique: Slow Motion Video Analysis (UberSense, Inc., Des Moines, IA, USA) or Coach’s Eye – Instant Replay (TechSmith Corporation, Okemos, MI, USA) record and break down sporting technique, allowing instant slow-motion feedback during practice. However, when using such apps one should be critical of their accuracy, reliability, and validity.

**Conclusion**

Coaches strive continually to improve the performance of their athletes. The most important aspect of their role is to provide athletes with a practice environment that is conducive to effective learning and success. When athletes are given the opportunity to compare their actual moves with the expected optimal performance, the probability of learning and correcting mistakes increases.

Appropriately employed technologically innovative resources can help coaches to advise their athletes and improve performance. The information offered by performance-analysis technology is accessible and easily interpretable by coaches and athletes. Since victory can be a matter of a few centimeters or hundredths of a second, such tools have plenty of practical potential.

As technologically provided feedback is critical for achieving success, almost every country that participates in the Paralympic Games employs performance-analysis feedback methods with its national teams and elite Paralympians.

Few coaches have the comfort level to integrate sophisticated performance-analysis technologies without the help of sport scientists. Coaches and athletes should be aware of the importance of integrating performance-analysis procedures at all levels, and not only when training elite athletes. Since technology changes rapidly, coaches and athletes should contact a reputable sport scientist to update their knowledge on new technologies.

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Chapter 9

Contribution of sport science to performance: Wheelchair rugby

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Introduction

Wheelchair rugby was “invented” in 1976 in Winnipeg, Canada, by a group of tetraplegic athletes who were looking for an alternative to wheelchair basketball. They wanted a sport in which players with reduced arm and hand function could participate equally. The sport they created, originally called “Murderball,” is now known as wheelchair rugby across the world (see Figure 9.1).

In 1993, the International Wheelchair Rugby Federation (IWRF) was established as a sport section of the International Stoke Mandeville Wheelchair Sports Federation, and in 1994, wheelchair rugby was officially recognized by the International Paralympic Committee (IPC) as a Paralympic sport. The first Wheelchair Rugby World Championships were held the following year in Nottwil, Switzerland, with eight teams competing. In 1996, wheelchair rugby was included as a demonstration sport in the Atlanta Paralympic Games, with six countries competing. It was recognized as a full medal sport for the first time at the 2000 Paralympic Games in Sydney, Australia, and is currently played in 27 countries, with another 22 countries in the development phase. For a more detailed description of the sport, and its rules and regulations, the reader is referred to the website of the International Wheelchair Rugby Federation (www.iwrf.com).

Since its appearance on the international sport scene, wheelchair rugby has been dominated by a handful of countries. Only five countries have been represented in the medal tallies of the World Championships since Nottwil (Switzerland) 1995 and in the Paralympic Games since Atlanta (USA) 1996: USA, Canada, Australia, New Zealand, and Japan (see Table 9.1). Although the sport is very well developed on the European continent, not one European country has yet reached World Championship or Paralympic Games medal status.

Wheelchair rugby was developed by tetraplegics for tetraplegics. The sport subsequently allowed access to athletes with polio, cerebral palsy, muscular dystrophy, multiple sclerosis, and amputations. According to the rules, to be eligible to play wheelchair rugby individuals must have an impairment that affects both the arms and the legs. Men and women compete on the same teams and in the same competitions, although at the highest level of competition female athletes are not well represented.

In Leuven (Belgium) in 1996, a unique group of individuals, all of them tetraplegics, some of them still in rehabilitation after their injury, decided to start playing wheelchair rugby (see Figure 9.2). There were only six of them in total, just enough for one line-up of four players in the game. These six individuals did not know they were at the start of a remarkable 20-year career in wheelchair rugby.
It was an honor and privilege for me to work with these remarkable athletes throughout their career, first as a physical trainer and scrimmage partner, later as their scientific counselor and their biggest fan. This chapter digs into the scientific literature on wheelchair rugby and each aspect of the sport scientific counseling process, as illustrated by the data collected in the Belgian national wheelchair rugby squad throughout the past 20 years. Most of these data are unique and have never been published.

Coach’s Corner

I would like to challenge coaches with the following puzzle about the unfairness of sport. To qualify for the Sydney 2000 Paralympic Games, European wheelchair rugby teams had to be in the top 4 at the 1999 European Championships, held in Nottwil, Switzerland. Belgium played 7 games at those European Championships, won 6, lost 1, but did not qualify for the Sydney Paralympic Games.

The wheelchair rugby chair

Athletes compete in manual wheelchairs that are specifically built for the sport. The rules include detailed specifications for wheelchairs to ensure safety and fairness. In international competition, all wheelchairs must meet these requirements (see Figure 9.3). All chair configurations meet maximal

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**Table 9.1** Wheelchair rugby final ranking in World Championships beginning in 1995 and in the Paralympic Games in 1996. Only those countries that took a medal (and Belgium) are presented. Never has a European country reached medal status.

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</thead>
<tbody>
<tr>
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<td>Toronto Canada</td>
<td>Sydney Australia</td>
<td>Gothenburg Sweden</td>
<td>Athens Greece</td>
<td>Christchurch New Zealand</td>
<td>Beijing China</td>
<td>Vancouver Canada</td>
<td>London UK</td>
<td>Odense Denmark</td>
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<td>7</td>
<td>7</td>
<td>12</td>
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</tr>
</tbody>
</table>

PG = Paralympic Games; WC = World Championships.
mobility criteria, as wheeled mobility and maneuverability are key determinants in wheelchair rugby performance (see also the section on wheelchair–player interface assessment).

The wheelchair rugby game

Wheelchair rugby is contested by two teams of four players, who are classified on a points system governed by the International Wheelchair Rugby Federation, ranging from 0.5 (most impaired) to 3.5 (least impaired). A total of 8 points are allowed on court at any one time. In this unique sport combining elements of rugby, ice hockey, and handball, players compete to carry the ball in firm control across the opposing team’s goal line. Contact between wheelchairs is permitted, and is in fact an integral part of the sport, as players use their chairs to hit, block, and hold opponents.

The movement dynamics in wheelchair rugby, specifically related to handling the wheelchair, can be defined as starting, sprinting, braking, turning (pivoting), and blocking; the latter movement characteristic is especially specific to wheelchair rugby. Players are allowed to pull backward in defense; furthermore, isometric holding, avoiding the opponent moving, is allowed. As maneuverability has priority over height, all players choose a low seat position (see the section on the wheelchair–player interface).

Rhodes et al. (2015a) conducted a time–motion analysis in 21 competitive matches over two international tournaments (2013 European and Americas Zonal Championships), using a radio-frequency-based indoor tracking system (Ubisense, Cambridge, UK). Six sensors installed around the court captured the locations of the players using...
Offensive wheelchairs

Offensive chairs are set up for speed and mobility and contain a front bumper and wings to prevent other wheelchairs from hooking it. These chairs are used by players with more function (2.0, 2.5, 3.0, 3.5).

Defensive wheelchairs

Defensive wheelchairs, like the one pictured on the left contain bumpers set up to hook and hold other players. These wheelchairs are most often used by players with less function (0.5, 1.0, 1.5).

Figure 9.3 Offensive and defensive wheelchair rugby chairs. Reproduced with permission of International Wheelchair Rugby Federation.

Small, lightweight tags, sending ultra-wideband radio signals and fixed to the foot strap of the wheelchairs; the tags’ sample frequency was 8 Hz (see Chapter 8 for more details). Results revealed that elite wheelchair rugby players covered approximately $4,213 \pm 626$ meters at a mean speed of $1.17 \pm 0.14$ meters/second. These results are comparable with those of Sarro et al. (2010), who reported a total distance of $4,540 \pm 817$ meters and mean speed values of $1.14 \pm 0.21$ meters/second. Rhodes et al. (2015a) indicated important differences in peak speed ($V_{\text{peak}}$) between athletes from different classes (see Table 9.2). These inter-class differences are confirmed in the data of the Belgian wheelchair rugby squad achieved in laboratory conditions on a motor-driven treadmill (see the later discussion of the maximal speed test), although differences between Class 0.5 and the other classes are much

Table 9.2 Descriptive statistics for movement variables during a standard wheelchair rugby quarter.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group by Functional Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I (n = 38)</td>
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<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Total distance (m)</td>
<td>881*†</td>
</tr>
<tr>
<td>Relative distance (m/min)</td>
<td>59.9*†</td>
</tr>
<tr>
<td>Mean speed (m/s)</td>
<td>1.01*†</td>
</tr>
<tr>
<td>Peak speed (m/s)</td>
<td>2.99*†</td>
</tr>
</tbody>
</table>

Note: $n =$ number of data sets per classification group.

*Significantly different from group II ($P < .05$). †Significantly different from group III ($P < .05$). ‡Significantly different from group IV ($P < .05$).

more pronounced in the Belgian sample (Class 0.5: $V_{\text{peak}} = \pm 2.5 \text{ m/s}$; Class 1.5: $V_{\text{peak}} = \pm 4.2 \text{ m/s}$; Class 3.5: $V_{\text{peak}} = \pm 4.4 \text{ m/s}$). It should be mentioned that the two Belgian 1.5 athletes were several times elected most valuable player (MVP) in international tournaments, which makes them perhaps less representative of the 1.5 Class. On the other hand, considering the non-, partial, or full availability of the triceps brachialis and its crucial role in handrim force generation, a linear relationship between the current classes and $V_{\text{peak}}$ can hardly be expected.

An important limitation of the indoor tracking system used by Rhodes et al. (2015a) is the restricted sampling frequency of 8 Hz, which does not allow for quantifying acceleration performance. Rhodes et al. (2015a) suggested the incorporation of accelerometry to provide a more in-depth insight into the high-intensity activities that may occur at low speeds in wheelchair rugby. Indeed, this approach would allow for the control of individual power generation and generate crucial information to individualize training programs and prevent overload and injuries.

Other than time–motion analyses, not many game analyses have been conducted to better understand successful performance in wheelchair rugby. Molik et al. (2008) used a wheelchair rugby statistics sheet, suggesting that “high-point” players (Classes 2.0–3.5) generally perform better than “low-point” players (Classes 0.5–1.5) in most of the ball-handling match activities such as points scored, interceptions, passes made, and passes caught (see Table 9.3). Because of their functional profile, low-point players typically act in a defensive on-court role, whereas high-point players (because of superior ball-handling tasks, wheelchair-handling proficiency, and speed occupying offensive on-court roles) scored 88% of the points (Molik et al., 2008).

Low-point players, and especially Class 0.5 players, are significantly disadvantaged in wheelchair rugby performance, as well as in wheelchair handling such as ball-handling proficiency, due to triceps brachialis paralysis. This disadvantage was stressed once more in the game efficiency parameters observed by Molik et al. (2008). No significant differences were indicated between any adjacent classes for the 11 parameters studied, except between Classes 0.5 and 1.0 for the sum of all points scored, assists, and balls passed (see Table 9.3).

If indeed low-point players with limited elbow-extension strength (Class 0.5 and 1.0) have reduced $V_{\text{peak}}$ wheelchair maneuverability and ball-handling proficiency, coaches could reduce their play time significantly by lining up four mid-point players. Rhodes et al. (2015b) suggested studying the effect of different line-up strategies (i.e., mid-point vs. high- and low-point line-ups) on activity profiles and performance in wheelchair rugby.

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**Coach’s Corner**

In wheelchair basketball, game statistics have evolved into a science in themselves, providing analytical information on game tactics, player and team strengths and weaknesses, composition of line-ups, etc. Wheelchair rugby coaches should develop wheelchair rugby statistical sheets, which could evolve into a more standardized analytical approach to be used by national sports federations and media to communicate in more depth about the game.

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An aerodynamic assessment of the wheelchair rugby athlete

Wheelchair rugby is a sport dominated by frequent, intermittent, short-term power demands superimposed on a background of aerobic
Table 9.3  Game efficiency parameters included for analysis: the sum of all points scored (PT), points scored after receiving a pass into the key area (PP), points scored after an athlete drove into the key area (PI), assists (AS), turnovers/losses of the ball (TO), steals/interceptions (ST), balls caught (CB), balls passed (PB), personal fouls (PF), percentage of balls caught (pCB), and percentage of passes caught by teammates (pPB).

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>PP</th>
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<th>TO</th>
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<td>(15.98)</td>
<td>(0.82)</td>
<td>(3.16)</td>
<td>(9.71)</td>
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*a*MRF classification.


activity (Goosey-Tolfrey and Leicht, 2013). Aerobic fitness is important in the sport to support sustained effort and accelerate recovery. Most tetraplegics are unable to engage in lower-limb aerobic exercise and must use upper-limb modes to assess aerobic capacity. This constraint is important, because in the able-bodied upper-limb exercise elicits a 40% lower peak power output ($P_{O_{\text{max}}}$) and a 25% lower peak oxygen uptake ($V_{O_{2\text{peak}}}$) compared to lower-limb exercise (Theisen, 2012). Additionally, tetraplegia adversely affects exercise capacity because of significant decreased voluntarily activated muscle mass in legs, trunk, and arms, reducing oxidative capacity and therefore maximal oxygen uptake and maximum caloric expenditure from exercise (Theisen, 2012). Moreover, as lesion level increases, sympathetic vasoconstrictive capacity gradually diminishes, reducing venous return and consequently stroke volume. In tetraplegia, two additional factors have negative impacts on exercise capacity. The first is that cardiac sympathetic innervation is absent and heart-rate increases can only be achieved by parasympathetic withdrawal and circulating catecholamines, limiting maximal heart rate to approximately 130 beats per minute (bpm). The second negative impact is that respiratory function is approximately 60% of normal values in tetraplegics (Theisen, 2012).

In laboratory conditions, maximal and submaximal aerobic testing of wheelchair rugby players should be done on a motor-driven treadmill, preferably with a deck length of 300 cm and width of 125 cm, equipped with a wheelchair stabilizer with integrated “range limiter” to insure the safety of the athlete. Positive energy exchange between treadmill and wheelchair facilitates wheeling and can be compensated by a standardized inclination of 1%. It should be noted that rolling resistance can deviate significantly between treadmills depending on the belt surface, with slat-style surfaces exhibiting an increased rolling resistance. The quality of the ball bearings of the wheelchair stabilizer should be excellent to minimize internal friction. The total resistance of the system can be measured by means of a drag test (van der Woude et al., 1986).

Different kinds of exercise protocols can be used for different purposes. The Belgian wheelchair squad has been assessed over the past 20 years with the following protocol:
- Warming up for 5 minutes at comfortable wheeling speed; belt inclination was 1% during the entire test.
- Maximal speed test, starting at 3 kilometers per hour (km/h), increasing velocity at 0.1 km/h per second, until the player cannot keep up with the belt speed. Maximal speed ($speed_{max}$) in km/h and lactate at maximal speed ($lactate_{speed_{max}}$) in millimole per liter (mmol/L) are registered.
- Incremental maximal aerobic test, starting at 3 km/h (if $speed_{max} < 11$ km/h) or 6.5 km/h (if $speed_{max} \geq 11$ km/h), increasing speed at 1 km/h per 2 minutes, until exhaustion. Lactate measurements are done in the last 15 seconds of each stage.

The maximal speed test serves a dual purpose: first, because of the maximal intensity and the short duration of the test (maximum 1–2 minutes), it provides a good indication of the player's anaerobic capacity; secondly, the test induces severe blood lactate accumulation, which is the starting point for the lactate minimum measurement in the incremental maximal aerobic test (for a full description, see Chapter 3). The lactate minimum test is used to determine the maximal lactate steady state (MLSS) for predicting endurance performance and designing individual training programs (see Figure 9.4).

The combination of reduced active muscle mass, impaired venous return, neurologically limited maximum heart rate, and decreased respiratory function significantly reduces exercise capacity in tetraplegics. Exercise capacity norms have been previously published for tetraplegics: $VO_{2peak}$ of $<7.6$ ml/kg/min is poor and $>16.95$ ml/kg/min is excellent (Janssen et al., 2002). These norms, although relevant for general fitness recommendations for tetraplegics, are not indicative for training guidelines for wheelchair rugby athletes, who exhibit $VO_{2peak}$ values of $21.1 \pm 6.3$ (Class 0.5), $26.4 \pm 6.1$ (Classes 1.0 and 1.5), $25.6 \pm 5.6$ (Classes 2.0 and 2.5), and $30.2 \pm 7.2$ ml/kg/min (Classes 3.0 and 3.5; Morgulec-Adamowicz et al., 2011). The career highs of the Belgian wheelchair rugby squad (see Figure 9.5) are comparable to the results of the Polish Wheelchair Rugby League players (Morgulec-Adamowicz et al., 2011). Peak performance data on both Belgian and Polish players were established in their personal competition chair on a motor-driven treadmill.

The laboratory screening described earlier provides coaches with comparative data about their athletes’ current aerobic physical condition versus previous assessments. Furthermore, coaches receive guidelines to develop individualized training programs. Such laboratory screening conducted once or twice per season should be complemented with field-based testing, athletes performing an aerobic test in their personal rugby wheelchair, and the interface (i.e., strapping and positioning) being set up as for competition. For reasons of standardization of rolling resistance and friction, tests should be conducted on their home training court. However, to be of practical use to wheelchair rugby coaches, the test should be easy to be set up and conducted by one coach, using only one wheelchair rugby court, within a short amount of time to avoid endangering the main purpose of the training session. Of course, the test should be standardized, accurate, reliable, and valid. According to a recent
Contribution of sport science to performance: Wheelchair rugby

Figure 9.5  Career (15y) individual VO\textsubscript{2peak} in Belgian wheelchair rugby squad.

review of field-based physiological testing (Goosey and Leicht, 2013), only Rhodes et al. (1981) tested tetraplegics using a Cooper test (maximum distance covered in 12 minutes).

For the first 10 years of their wheelchair rugby career, the Belgian rugby team had to perform a 12-minute Cooper test (Cooper, 1968) around the 28 × 15 meter court a minimum of six times a year (see Figure 9.6). Early in their careers, all players, except the 0.5 player, demonstrated a progressive increase in distance covered in 12 minutes; however, their performance did not correlate well with the laboratory treadmill test. In Figure 9.7, the Cooper test and laboratory aerobic test results of a 1.5 player are compared. After an initial increase in field test results, mainly due to peripheral physiological adaptations, enhanced propulsion technique, better equipment, and optimized wheelchair-athlete interface, a plateau in performance was reached. In the laboratory, however, no changes in VO\textsubscript{2peak} were noticed. In Figure 9.7, intra-athlete variability in the laboratory tests (only one measurement per year at different times of periodization) is much higher than in the field tests (an average of several measurements per year). Unfortunately, in 2007 the floor of the home training court was renewed and adapted to prevent running injuries, increasing the rolling resistance for wheelchair rugby players to an unacceptable level.

An alternative field-based test to measure aerobic fitness is the multi-stage field test (MSFT), which has been used in several formats: shuttle run (Vanlandewijck et al., 1999) and octagonal (Van der Thommen et al., 2002). The 25-meter shuttle run developed by Vanlandewijck et al. (1999) resulted in low VO\textsubscript{2}-predictive values ($r^2 = 0.41$). This was explained partially by the 180° turns that the players have to make after each 25 meters. In a subsequent investigation (Vanlandewijck et al., 2006), 12 wheelchair basketball players performed the 25-meter shuttle run three times in a random order with an interval of a minimum of 48 hours. Each shuttle run test (SR) had a specific turn modus: width of 150 centimeters (SR\textsubscript{3X}), width of three times the rear wheel base (SR\textsubscript{150}), and free width (SR\textsubscript{free}). In Table 9.4, it is shown that the width of the turn has a significant impact on SR performance, without changing the metabolic response (heart rate [HR] and lactate).

Coach’s Corner

Even though a perfect field test to predict aerobic capacity in wheelchair rugby players does not exist, the oval MSFT provides a good estimate of the player’s physical condition. If the player changes equipment, wheelchair configuration, or the test is conducted on a different court, the tests become non-comparable.

As it was expected that 180° turns would have a dramatic effect on wheelchair rugby players’ shuttle run performance, forcing the players after each
Figure 9.6  Cooper test results over a decade of five players from the Belgian wheelchair rugby team. Results are an average of at least six tests per year. The legend indicates lesion level, (in)completeness of the lesion, and wheelchair rugby class.

A straight line to decelerate, to turn, and to accelerate from almost a standstill, an oval MSFT was developed, changing the two 180° turns into four 90° curves. Because of the rounded corners (see Figure 9.8), wheelchair handling proficiency in the oval MSFT is minimized.

Figure 9.7  Career Cooper test results (1997–2006) versus VO₂peak measured during a ramp test in the laboratory for a 1.5 wheelchair rugby player.
Table 9.4  Comparison of 25 m shuttle run performance with turning width of 150 cm (SR_{150}), 3 times the rear wheel base (SR_{3X}), and free width (SR_{free}).

<table>
<thead>
<tr>
<th></th>
<th>SR_{150}</th>
<th>SR_{3X}</th>
<th>SR_{free}</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HR (bpm)</strong></td>
<td>X</td>
<td>182.1</td>
<td>181.9</td>
<td>182.5</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>18.2</td>
<td>16.5</td>
<td>17.4</td>
</tr>
<tr>
<td><strong>Lactate (mmol/L)</strong></td>
<td>X</td>
<td>10.1</td>
<td>8.8</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.4</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>SR performance (s)</strong></td>
<td>X</td>
<td>475</td>
<td>510</td>
<td>565</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>97.3</td>
<td>94.0</td>
<td>100.6</td>
</tr>
</tbody>
</table>

Anaerobic assessment of the wheelchair rugby athlete

The ability repeatedly to produce a high power output or sprint speed is a key performance component in wheelchair rugby. Anaerobic power is defined as the maximum amount of power that can be generated using anaerobic (immediate and short-term) sources of energy production. Anaerobic capacity is defined as the average power that can be developed over a given period of time using anaerobic energy sources.

The Wingate anaerobic test (WAnT), which was developed in Israel in the mid-1970s for able-bodied individuals (Bar-Or, 1987), has been adapted for wheelchair users, assessing anaerobic power and capacity through arm cranking in laboratory conditions (Jacobs et al., 2004). For more details on the

Figure 9.8  Oval multi-stage field test: players start at the central of the three cones marking the curve (●). The protocol begins at 3 km/h (tetraplegics) or 6 km/h (paraplegics); the speed is increased by 0.5 km/h per min. The circumference of the oval is 80 m. Feedback is given at each opposite corner, every 40 m. The wheelchair rugby player should be between the first and the third cones at the feedback signal. If the player is too late two consecutive times notwithstanding encouragement, the player has to abandon the test and the distance covered is registered. The table shows normative data. Tetraplegics are wheelchair rugby players. (*: 180s [3 min] added to the total time for reasons of comparison with tetraplegics.)
laboratory protocols, the reader is referred to Chapter 13 in the handbook *The Paralympic Athlete* (Vanlandewijck and Thompson, 2011).

In 1976, Bar-Or (1987) tried to develop a field test for the assessment of anaerobic power and capacity in wheelchair users, allowing coaches to conduct field anaerobic assessments regularly throughout the season. However, the validity of the field tests, an important issue for the correct interpretation of outcomes, remained a major issue. In able-bodied sports, the Running Anaerobic Sprint Test (RAST) was developed by Wolverhampton University (UK) adapted from the original WAnT, measuring peak power (PO\text{peak}), mean power (PO\text{mean}), and fatigue index (FI) (Zacharogiannis et al., 2004). RAST data have been significantly correlated with WAnT data collected in laboratory conditions (Zacharogiannis et al., 2004). The RAST involves six sprints over 35 meters with a 10-second recovery between sprints. By measuring body mass and running times, it is possible to determine the power of effort in each sprint: 

\[
PO = \frac{body\ mass \times distance^2}{time^3}
\]

Based on the RAST procedure, Verschuren et al. (2005) developed the Muscle Power Sprint Test (MPST) for children with cerebral palsy to measure short-term muscle power, first for running performance (Verschuren et al., 2005), and later adapted to children with cerebral palsy who use self-propelled wheelchairs (Verschuren et al., 2013). Significant correlations between the performances on the arm-cranking WAnT and MPST were found (PO\text{peak}; \( r = 0.91, p < 0.001 \); PO\text{mean}; \( r = 0.88, p < 0.001 \)).

The anaerobic power and capacity of the Belgian wheelchair rugby squad have been assessed with an adapted version of the MPST, according to the RAST procedure. The athletes used their own rugby wheelchair, repeating eight all-out sprints over a distance of 12 meters. The time was recorded by means of Micro Gates (Kit Racetime2 Light, Bolzano, Italy). Between each sprint, the participant had 5 seconds to turn and get back to the starting position, placing the front wheels on a taped line 0.5 meters from the first Micro Gate (see Figure 9.9). As only the straight 12 meters sprinting time is recorded, wheelchair handling/turning proficiency cannot have an impact on performance. In Table 9.5, MPST results of four players of rugby Classes 0.5, 1.5, 2.0, and 3.0 are provided as a reference.

The following variables were calculated: PO\text{peak}, a measure of the highest power output (PO), which provides information about strength and maximal sprint speed; PO\text{min}, the lowest PO achieved and needed to calculate FI; PO\text{mean}, the average PO of the eight sprints, indicating the athlete’s ability to maintain anaerobic performance over time; and FI, the lower the value for which, the higher the athlete’s ability to maintain anaerobic performance. Unfortunately, no normative data are available.

**Figure 9.9** Start of the Muscle Power Sprint Test.

Body weight is important in a game like wheelchair rugby. In being hit by or hitting an opponent, body weight can make a significant difference. However, for most key activities in wheelchair rugby (i.e., fast acceleration, sprinting, and maneuvering) the ideal body is not the corpulent body. For any athlete, ideal body weight depends on the performance determinants of his or her specific sport. In able-bodied sport, rowers tend to be tall and heavy, gymnasts small and flexible, and sprinters muscular and lean. Athletes should monitor their body weight during their career and should understand the weight/performance relationship.
Table 9.5  Reference data from the Belgian wheelchair rugby squad on the MPST.

<table>
<thead>
<tr>
<th>BW + WC (kg)</th>
<th>CLASS 0.5</th>
<th>CLASS 1.5</th>
<th>CLASS 2.0</th>
<th>CLASS 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>76</td>
<td>86</td>
<td>80</td>
<td>87</td>
</tr>
<tr>
<td>Sprint / PO 1</td>
<td>5.21</td>
<td>77.4</td>
<td>4.41</td>
<td>144.4</td>
</tr>
<tr>
<td>Sprint / PO 2</td>
<td>5.42</td>
<td>68.7</td>
<td>4.45</td>
<td>140.5</td>
</tr>
<tr>
<td>Sprint / PO 3</td>
<td>5.54</td>
<td>64.4</td>
<td>4.60</td>
<td>127.2</td>
</tr>
<tr>
<td>Sprint / PO 4</td>
<td>5.67</td>
<td>60.0</td>
<td>4.63</td>
<td>124.8</td>
</tr>
<tr>
<td>Sprint / PO 5</td>
<td>5.79</td>
<td>56.4</td>
<td>4.76</td>
<td>114.8</td>
</tr>
<tr>
<td>Sprint / PO 6</td>
<td>5.94</td>
<td>52.2</td>
<td>4.86</td>
<td>107.9</td>
</tr>
<tr>
<td>Sprint / PO 7</td>
<td>6.00</td>
<td>50.7</td>
<td>4.94</td>
<td>102.7</td>
</tr>
<tr>
<td>Sprint / PO 8</td>
<td>6.20</td>
<td>45.9</td>
<td>4.99</td>
<td>99.7</td>
</tr>
<tr>
<td>Σ sprint / PO 1-8</td>
<td>45.77</td>
<td>475.7</td>
<td>37.64</td>
<td>962</td>
</tr>
<tr>
<td>PO&lt;sub&gt;peak&lt;/sub&gt;</td>
<td>77.4</td>
<td>144.4</td>
<td>122.3</td>
<td>185.8</td>
</tr>
<tr>
<td>PO&lt;sub&gt;min&lt;/sub&gt;</td>
<td>45.9</td>
<td>99.7</td>
<td>80.1</td>
<td>109.1</td>
</tr>
<tr>
<td>PO&lt;sub&gt;mean&lt;/sub&gt;</td>
<td>59.5</td>
<td>120.3</td>
<td>96.8</td>
<td>145.8</td>
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<tr>
<td>FI</td>
<td>0.69</td>
<td>1.19</td>
<td>1.07</td>
<td>2.15</td>
</tr>
</tbody>
</table>

Coach’s Corner

Even though no normative data for the MPST are available yet, the MPST provides coaches with very relevant information on crucial aspects of wheelchair rugby performance: sprint power and lactate tolerance. Coaches should be aware that MPST data collected in different sport halls, with a different floor surface, are non-comparable.

Coaches should monitor body composition, or body fat percentage, as a useful supplement to monitoring body weight. Optimal body fat percentage is that which is associated with the best training and competitive performances. An increase in body fat percentage could indicate that adjustment is needed in food intake to better match current training demands. Dual-energy X-ray absorptiometry (DXA) is increasingly being used to measure body composition in various settings, including athletic training/performance. This methodology is rapid, relatively inexpensive, and uses only a small amount of ionizing radiation (Buehring et al., 2014). The ability to evaluate not only total body fat/lean mass ratios, but also fat/lean mass ratios in specific regions such as the upper and lower extremities and the trunk, is a distinct advantage of DXA compared with other measures of body composition, such as bioelectrical impedance analysis (BIA), hydrodensitometry (underwater weighing), or air displacement plethysmography (BOD POD, Life Measurement Instruments, Concord, USA). Total and regional body composition data in spinal cord–injured athletes have been published by Inukai et al. (2006); differences in total percentage body fat between wheelchair basketball (24.7% ± 4%), wheelchair tennis (27.3% ± 7.4), and track wheelchair racing (20.9% ± 4.4) athletes were not significant. However, upper extremity percentage fat (left arm 20.7% ± 7.5; right arm 19.8 ± 7.2) was significantly lower than trunk (23.0% ± 7.9) and lower extremities (left leg 35.2% ± 7.7; right leg 35.3% ± 7.6) for the total group of paraplegic athletes. Total exercise duration per week was positively related to fat percentage in total body, upper extremities, and trunk; no impact was shown in the lower extremities.

Percentage of total or regional body fat, however, is less informative in a spinal cord–injured population compared to total body or regional fat/lean mass ratios. In Table 9.6, the impact of spinal cord injury during the first year after injury is presented for tetraplegic and paraplegic individuals (Singh et al., 2014). Muscle atrophy results in a dramatic ratio increase in the legs in tetra- as well as paraplegics. The same deterioration, although less pronounced, is seen in the upper extremities and trunk in tetraplegics, whereas the impact is minimal in paraplegics. Normative data for male and female able-bodied student athletes (Buehring et al., 2014) and exemplary data for male wheelchair
**Table 9.6** Regional fat/lean mass ratios in tetraplegics and paraplegics during the first year after injury; left panel. Normative data for male and female able-bodied student athletes and exemplary data for male wheelchair rugby athletes Classes 0.5, 1.0, and 2.5 are presented in the right panel.

<table>
<thead>
<tr>
<th></th>
<th>Tetraplegics</th>
<th>Paraplegics</th>
<th>AB-athletes</th>
<th>Wheelchair Rugby</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>1 year</td>
<td>male 0.5</td>
<td>1.80 1.67 1.89 1.87 1.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>female 1.5</td>
<td>1.67 1.87 1.78</td>
</tr>
<tr>
<td>Height (m)</td>
<td>NA</td>
<td>1.80</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>NA</td>
<td>65.0</td>
<td>23.5</td>
<td></td>
</tr>
<tr>
<td>BMI (kg.m$^2$)</td>
<td>23.1</td>
<td>61.2</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>BF (%)</td>
<td>24.7</td>
<td>24.4</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>L Arm ratio</td>
<td>23.7</td>
<td>29.4</td>
<td>28.1</td>
<td></td>
</tr>
<tr>
<td>R Arm ratio</td>
<td>25.4</td>
<td>32.8</td>
<td>26.2</td>
<td></td>
</tr>
<tr>
<td>Trunk ratio</td>
<td>34.9</td>
<td>42.6</td>
<td>28.8</td>
<td></td>
</tr>
<tr>
<td>L Leg ratio</td>
<td>36.7</td>
<td>55.3</td>
<td>48.9</td>
<td></td>
</tr>
<tr>
<td>R Leg ratio</td>
<td>40.2</td>
<td>54.4</td>
<td>50.8</td>
<td></td>
</tr>
<tr>
<td>Tot ratio</td>
<td>34.1</td>
<td>43.3</td>
<td>33.8</td>
<td></td>
</tr>
</tbody>
</table>


Wheelchair rugby athletes Classes 0.5, 1.0, and 2.5 (Vanlandewijck, unpublished data) are also presented. Even though the total percentages of body fat are not extremely different, the regional ratios clearly indicate the excellent and very good shape of the low-point players compared to the dramatic condition of the upper extremities and trunk of the 2.5 players. DXA body composition is most appealing for serial measurement to monitor body composition changes over time in order to monitor training programs and/or injury and subsequent rehabilitation (Buehring et al., 2014).

Over the past 15 years, the body composition of the Belgian wheelchair rugby squad has been evaluated through underwater weighing and skinfold measurement. Players representing Classes 0.5, 1.5, 2.0, and 3.0 were able to keep their body weight under control through their entire career, from 1997 to 2013 (see Table 9.7).

Accurate anthropometric measurements are relatively easy to obtain from athletes with spinal cord injury, employing only minor deviation from standardized procedures; furthermore, the required equipment (metric-ruled measuring tapes and skinfold calipers) is relatively inexpensive. However, population-specific prediction equations to estimate total body and regional body composition are currently not available, and the relationships among individual anthropometric measures and performance- or health-related outcomes have not been determined (Clasey and Gater, 2007).

**Wheelchair rugby nutrition assessment**

In wheelchair rugby, a sport dominated by frequent, intermittent, short-term power demands superimposed on a background of aerobic activity, a lean body with a good portion of fast-twitch IIa and IIb fibers (see Chapter 3) is definitively advantageous. Of course, the athlete’s body should be nurtured and hydrated optimally; the reader is referred to the chapters on exercise physiology (Chapter 3) and sport medicine (Chapter 4) for more detailed information and guidelines on nutrition and hydration.

Specific to wheelchair rugby athletes, the study of Black et al. (2013) should be mentioned. The starting point was the observation that wheelchair rugby athletes tend to ingest large volumes of fluid during training and competition. As athletes with tetraplegia do not sweat below the lesion, the fluid intake is probably in excess of their requirements and can lead to low blood sodium concentrations and hyponatremia. It has been theorized that those with tetraplegia try to promote thermal comfort by drinking (Price and Campbell, 2003). The aim of Black et al.’s (2013) study was to investigate relationships between blood sodium concentrations, fluid intake, and ratings of thermal comfort among those with tetraplegia during a day with two typical wheelchair rugby training sessions. It
Table 9.7 Career body composition data of four Belgian wheelchair rugby players, Class 0.5, Class 1.5, Class 2.0, and Class 3.0.

<table>
<thead>
<tr>
<th>Class</th>
<th>Date 1</th>
<th>Date 2</th>
<th>Date 3</th>
<th>Date 4</th>
<th>Date 5</th>
<th>Date 6</th>
<th>Date 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23/07/2009</td>
<td>29/10/2010</td>
<td>16/03/2011</td>
<td>20/01/2012</td>
<td>27/06/2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.89</td>
<td>1.89</td>
<td>1.89</td>
<td>1.89</td>
<td>1.89</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.66</td>
<td>61.97</td>
<td>63.54</td>
<td>58.2</td>
<td>61.7</td>
<td>58.2</td>
<td></td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>11.59%</td>
<td>10.93%</td>
<td>11.75%</td>
<td>9.99%</td>
<td>10.64%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>7.38</td>
<td>6.77</td>
<td>7.47</td>
<td>5.81</td>
<td>6.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>56.28</td>
<td>55.2</td>
<td>56.07</td>
<td>52.39</td>
<td>55.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum 12 skinfolds</td>
<td>86.4</td>
<td>81.2</td>
<td>84.6</td>
<td>67.7</td>
<td>78.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1.5</td>
<td>30/06/1997</td>
<td>30/06/2004</td>
<td>18/05/2009</td>
<td>9/11/2010</td>
<td>16/03/2011</td>
<td>20/01/2012</td>
<td>27/06/2013</td>
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<tr>
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<td>1.87</td>
<td>1.87</td>
<td>1.87</td>
<td>1.87</td>
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<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
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<td>70.9</td>
<td>67.22</td>
<td>67.95</td>
<td>69.7</td>
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<tr>
<td>Body fat (%)</td>
<td>15.35</td>
<td>14.12</td>
<td>16.73%</td>
<td>17.41%</td>
<td>16.86%</td>
<td>16.55%</td>
<td>16.04%</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>10.59</td>
<td>10.01</td>
<td>11.25</td>
<td>11.83</td>
<td>11.75</td>
<td>11.54</td>
<td>11.23</td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>58.41</td>
<td>58.41</td>
<td>55.97</td>
<td>56.12</td>
<td>57.95</td>
<td>58.18</td>
<td>58.77</td>
</tr>
<tr>
<td>Sum 12 skinfolds</td>
<td>39.60</td>
<td>100.3</td>
<td>112.76</td>
<td>97.1</td>
<td>93.47</td>
<td>92.4</td>
<td></td>
</tr>
<tr>
<td>Class 2.0</td>
<td>30/06/1997</td>
<td>30/06/2004</td>
<td>11/05/2009</td>
<td>29/10/2010</td>
<td>16/03/2011</td>
<td>20/01/2012</td>
<td></td>
</tr>
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<td>1.83</td>
<td>1.83</td>
<td>1.83</td>
<td>1.83</td>
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<td></td>
</tr>
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<td>Weight (kg)</td>
<td>72</td>
<td>67.8</td>
<td>67.5</td>
<td>63.96</td>
<td>64.85</td>
<td>65.52</td>
<td></td>
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<tr>
<td>Body fat (%)</td>
<td>20.17</td>
<td>16.97</td>
<td>22.4</td>
<td>21.42</td>
<td>20.52</td>
<td>20.61%</td>
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</tr>
<tr>
<td>Body fat (kg)</td>
<td>14.52</td>
<td>11.5</td>
<td>15.12</td>
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<td>13.31</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>57.48</td>
<td>56.3</td>
<td>52.38</td>
<td>50.26</td>
<td>51.54</td>
<td>52.02</td>
<td></td>
</tr>
<tr>
<td>Sum 12 skinfolds</td>
<td>58.70</td>
<td>179.8</td>
<td>149.3</td>
<td>145.3</td>
<td>138.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 3.0</td>
<td>30/06/1997</td>
<td>30/06/2004</td>
<td>18/05/2009</td>
<td>29/10/2010</td>
<td>16/03/2011</td>
<td>20/01/2012</td>
<td>27/06/2013</td>
</tr>
<tr>
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<td>1.78</td>
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<td>1.78</td>
<td>1.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73</td>
<td>78.4</td>
<td>79.32</td>
<td>67.78</td>
<td>70.51</td>
<td>69.56</td>
<td>72.7</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>14.41</td>
<td>19.27</td>
<td>21.41%</td>
<td>14.87%</td>
<td>15.00%</td>
<td>15.23%</td>
<td>15.36%</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>10.52</td>
<td>15.15</td>
<td>16.98</td>
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<td>10.58</td>
<td>10.59</td>
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<td>Fat free mass (kg)</td>
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<td>63.3</td>
<td>62.34</td>
<td>57.7</td>
<td>59.93</td>
<td>58.97</td>
<td>61.53</td>
</tr>
<tr>
<td>Sum 12 skinfolds</td>
<td>34.20</td>
<td>174.2</td>
<td>97.1</td>
<td>103.4</td>
<td>101.6</td>
<td>102.8</td>
<td></td>
</tr>
</tbody>
</table>

* = sum of 4 skinfolds.

was remarkable that during both training sessions athletes gained body mass (+0.41% in the morning session and +0.69% in the afternoon session). Over the course of the day, blood sodium concentrations significantly declined. This is despite the athletes consuming a sodium-containing meal between training sessions. During the day, two players recorded blood sodium concentrations of 135 mmol/L, with another five players providing blood samples with a sodium concentration of 136 mmol/L. Given that the established cutoff for hyponatremia is 135 mmol/L, over half the players reported asymptomatic hyponatremic or approaching an asymptomatic hyponatremic state over the course of the training day. Thermal comfort increased (toward “too hot”), with 38.7% and 31.0% during the morning and afternoon sessions, respectively. Black et al. (2013) concluded that athletes with tetraplegia ingest fluid in excess of their requirements, largely in an attempt to reduce thermal discomfort. Given the low blood sodium concentrations observed in this study, such behavior may increase the risk of hyponatremia. Therefore, specific recommendations for individuals with tetraplegia are required, with more emphasis on the risk of hyponatremia. These recommendations may include the provision of drinks with added sodium or for drinks to be served at cold temperatures.

**Coach's Corner**

At present, there are no fluid-intake guidelines that can be easily implemented for wheelchair athletes with tetraplegia. Hydration should be approached individually, taking into consideration the complexity of the athlete’s performance, bladder management, thermal comfort, and fluid and mineral homeostasis.
Wheelchair-player interface assessment in wheelchair rugby

The horizontal and vertical positions of the center of gravity ($C_g$) of the wheelchair-player combination (WPC) determine the mobility-stability relationship of the WPC. Optimizing the interface for mobility implies a rearward and downward shift of $C_g$ in relation to the axle of the rear wheel. A rearward shift of $C_g$ will decrease the rolling resistance and reduce the inertial rotation torque; a downward shift of $C_g$ will decrease the inertial reaction torque on the trunk and wheelchair frame when accelerating the WPC, and will make the handrim more accessible to generate power.

\[ x = (F_1 \cdot d) \cdot (m \cdot g)^{-1} \]

\[ F_1 = \text{the weight on the front wheels} \]
\[ d = \text{the horizontal distance between the rear- and the front-wheel axle} \]
\[ m \cdot g = \text{the total mass of the WPC} \]

The y-coordinate of $C_g$ was calculated as $y = x \cdot \cotg(\text{angle}_{\text{incl}})$. $\text{angle}_{\text{incl}}$ was defined as the angle over which the WPC had to be inclined to decrease $x$ to 0. With the anti-tipping devices allowed in basketball and rugby, the optimal fore-aft position in basketball and rugby is with the $C_g$ close to zero. Because of the dynamics of the game, all wheelchair rugby players (Classes 0.5–3.5) prefer to maximize mobility, keeping the $C_g$ as low as possible ($y = 28.5 \pm 1.1$ cm). This position is still lower compared to low-point basketball players (Classes 1.0–2.5: $y = 32.2 \pm 1.8$ cm). Extreme hip flexion to increase trunk stability in wheelchair rugby players is responsible for this difference. The average y-coordinate of $C_g$ of the high-point basketball players (Classes 3.0–4.5) was $39.7$ cm with a standard deviation (SD) of $5.1$ cm. The variability within this group can be explained by the height of the players, only tall players benefitting from a high seat position (e.g., rebounding).

In wheelchair rugby, players with tetraplegia often make use of excessive abdominal binding or strapping. The impact of abdominal strapping is manifold. West \textit{et al.} (2014a) demonstrated in ten Paralympic wheelchair rugby players with motor-complete SCI (C5–C7) that abdominal binding increased the distance covered during a two-times 4-minute push test (first 4-min test: $700 \pm 75$ m unbound versus $713 \pm 83$ m bound; second 4-min test: $694 \pm 81$ m unbound versus $722 \pm 84$ m bound). The impact of abdominal binding was also seen in the acceleration/deceleration test. The test consisted of a 5-meter forward push, a 2.5-meter backward push, and a 12.5-meter forward push. The wheelchair rugby players completed the test three times with a 60-second rest between each trial. The fastest time with abdominal binding ($10.07 \pm 0.59$ seconds) was significantly faster than the fastest time in unbound condition ($10.25 \pm 0.72$ seconds).

Coach's Corner

Optimal seat height in wheelchair rugby is always a compromise between comfort, trunk stability, and dynamic reach, trunk and arm length of the player, and position-related tasks on the court.

Vanlandewijck \textit{et al.} (2001) measured the position of $C_g$ in wheelchair basketball and the Belgian wheelchair rugby squad (unpublished data). The fore-aft coordinate ($x$) of $C_g$ of the WPC, with respect to the axle of the rear wheel, was calculated as:

\[ x = (F_1 \cdot d) \cdot (m \cdot g)^{-1} \]

Next to the exercise physiological benefits of abdominal binding, tetraplegic wheelchair rugby players also use this kind of strapping to increase trunk stability, which allows the arms to generate more power on the handrims, and protects the players from losing balance when hit by an opponent. Coaches should be aware that improved trunk stability also leads to decreased trunk mobility, which has a negative impact on trunk range of action. Furthermore, excessive abdominal strapping can evoke autonomic dysreflexia.

In a follow-up study, eight Paralympic wheelchair rugby players with motor-complete lesion levels (C5–C7) performed submaximal and maximal incremental exercise tests on a treadmill, both with and without abdominal binding (West \textit{et al.}, 2014b). The binding-induced changes in intra-abdominal pressure were accompanied by increases
in whole-body oxygen (O$_2$) uptake and decreases in systemic blood lactate at high relative intensities of exercise (95% of VO$_{2\text{peak}}$). West et al. (2014b) argued that the binding-induced increase in O$_2$ uptake relates to an improvement in central hemodynamics. The increases in abdominal pressure due to application of the binder may be expected to decrease vascular compliance, increase mean vascular pressure, and therefore increase stroke volume.

**Wheelchair rugby skill proficiency assessment**

The need to study the skill performance of athletes with impairment is well established. Valid and reliable sport skill tests enable coaches systematically to assess players’ progress, individualize instruction and practice, and provide individualized feedback to motivate players. However, compared to able-bodied sport, skill proficiency in dynamic wheelchair sports such as basketball, rugby, and tennis is hardly studied.

As a wheelchair basketball coach, coaches do not allow a player to miss a lay-up, the easiest shot in the game. If a terrible execution of the lay-up brings the ball through the hoop, no complaints. Wrong! Wheelchair rugby coaches want low-point players to put up a screen, to create space for the teammate high-point player carrying the ball. If the screen is not put up perfectly, but the high-point player succeeds in scoring, no complaints. Wrong! According to Owen (1982) and Hedrick et al. (1994), two of the most charismatic wheelchair basketball coaches, the perfection of fundamental individual skills is probably the most significant contributor to success in basketball, wheelchair or otherwise. Of course, this is not any different for other dynamic wheelchair sports such as tennis and rugby.

The first attempt to develop a wheelchair rugby skill proficiency test was by Yilla and Sherrill (1998), introducing the Beck Battery of quad rugby skill tests. The battery consists of five wheelchair rugby–specific tests: maneuverability with the ball; pass for accuracy; picking; sprinting; and pass for distance. It was concluded that the Beck Battery skill tests are valid and reliable for adult males aged 18–51 years. Although referred to several times in the wheelchair rugby literature, the Beck Battery has not been applied systematically and normative data have not been developed. Also, the suggestions by Yilla and Sherrill (1998) to refine each sub-test and to check the generalizability of the test to the mature wheelchair rugby athlete have not been accomplished.

**Coach’s Corner**

Most coaches are creative and find a way to measure their athletes’ wheelchair rugby skill proficiency. The IWRF should take the initiative to collect this information and develop a standardized skill proficiency test and start developing normative data. This will soon become a popular tool in wheelchair rugby clinics for coaches and classification workshops.

An alternative wheelchair rugby skill test battery has been published by BlazeSports (Gumbert, 2004). The Skill Assessment Test has been adapted from US Paralympics rugby and includes a passing skill test; sprints; endurance sprints; up and backs; and slalom (see Figure 9.10). The Skill Assessment Test is easier to set up and administer than the Beck Battery. However, normative data as well as psychometric properties of the Skill Assessment Test could not be retrieved.

As stated earlier, the perfection of fundamental individual skills is probably the most significant contributor to wheelchair rugby. Measuring the outcome of skill performance, as through a Beck Battery or Skill Assessment Test, will reveal whether the task is done well or not. However, the quality of the technical execution, or in other words the level of maturity of the skill, has not been evaluated. To ensure that critical and fundamental individual skills are developed, instructional objectives must be identified for individual players (Hedrick et al., 1994). Therefore, coaches must assess the individual skill proficiency level of wheelchair rugby players in a qualitative way. Zwakhoven et al. (2003) developed an observation protocol to assess the quality of the most relevant skills in wheelchair basketball. The first task in the development of the protocol was to select observable performance criteria of seven specific ball-handling skills, which represented the mature
pattern for each of the skills. The seven skills were dribble, bounce-stop, bounce-spin, passing, catching, shot, and lay-up. An example of an observable performance criterion for wheelchair basketball is provided in Table 9.8 (Zwakhoven et al., 2003).

Observable performance criteria for wheelchair rugby skills are not available at this time. However, BlazeSports (Gumbert, 2004) has provided a basic description of the fundamental skills in wheelchair rugby (see Table 9.9).

Starting from handbooks and manuals, such as the one from BlazeSports (Gumbert, 2004), and through expert (coaches’) opinion, standardized wheelchair rugby–specific observation protocols for qualitative analysis of skill proficiency can be constructed. The development of such a tool would be welcomed by coaches and trainers to detect the players’ flaws and shortcomings in an objective way, and to give them appropriate individual training and guidelines. Such a tool could be used to observe players during training, but also during actual game play.

Wheelchair rugby anti-doping assessment

Elite Olympic and Paralympic athletes have at least one characteristic in common: they want to

<table>
<thead>
<tr>
<th>Table 9.8</th>
<th>Performance criteria for “wheelchair basketball dribble.”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The ball is dribbled in front and close to the side of the wheelchair</td>
<td></td>
</tr>
<tr>
<td>2. The ball is played from the wrist with minimal elbow flexion</td>
<td></td>
</tr>
<tr>
<td>3. Eyes are not fixed on the ball; player keeps overview of the game while dribbling</td>
<td></td>
</tr>
<tr>
<td>4. The wheelchair is continuously positioned between the ball and a defensive player</td>
<td></td>
</tr>
<tr>
<td>5. Player keeps on dribbling while moving the wheelchair</td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Table 9.9</th>
<th>Fundamentals of the wheelchair rugby dribble.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamentals of the dribble: The ball should be bounced between the front caster and the rear wheel. There is usually a bit more floor space in this area. Be cautious of bouncing directly over the wheel as most rookies bounce the ball off the base of the cambered wheels. Do not bounce the ball too hard – just enough to get your hand back under it about waist level and pull it back into your possession. The quicker and more diverse (right &amp; left hand) your dribbling the more effective you are as a player. Learn to dribble without having to watch the ball.</td>
<td></td>
</tr>
</tbody>
</table>

Source: Gumbert 2004.
Table 9.10  Review of literature in able-bodied populations on the impact of sildenafil citrate on peak exercise capacity (Peak ex cap) and exercise performance (Ex perf) at sea level (SL), moderate altitude (MA), and high altitude (HA). A/C = acute/chronic; mg = milligrams sildenafil citrate dose; TT = time trial; K = kilometers

<table>
<thead>
<tr>
<th>N</th>
<th>HA</th>
<th>A/C</th>
<th>mg</th>
<th>Peak ex cap</th>
<th>Submax ex cap</th>
<th>Ex perf</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>5,245m</td>
<td>A/C</td>
<td>50</td>
<td>max</td>
<td>Yes Alt PO&lt;sub&gt;peak&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>SL</td>
<td></td>
<td>50/100</td>
<td>max</td>
<td>No SL VO&lt;sub&gt;2&lt;/sub&gt;/PO&lt;sub&gt;peak&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>5,000m</td>
<td>A</td>
<td>100</td>
<td>max</td>
<td>Yes Alt VO&lt;sub&gt;2peak&lt;/sub&gt;</td>
<td>50% max</td>
</tr>
<tr>
<td>12</td>
<td>4,350m</td>
<td>A/C</td>
<td>40 x 3</td>
<td>max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>3,874m</td>
<td>A</td>
<td>50/100</td>
<td>max</td>
<td>Yes Alt PO&lt;sub&gt;peak&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>4,300m</td>
<td>A</td>
<td>100</td>
<td>max</td>
<td>No Alt VO&lt;sub&gt;2peak&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>4,300m</td>
<td>C (18h)</td>
<td>40 x 3</td>
<td>max</td>
<td>40% VO&lt;sub&gt;2peak&lt;/sub&gt;SL</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>3,900m</td>
<td>A</td>
<td>50</td>
<td>max</td>
<td>No Alt PO&lt;sub&gt;peak&lt;/sub&gt;</td>
<td></td>
</tr>
</tbody>
</table>

enhance performance. Only a few of the elite athletes will use illegal means or substances to reach this goal. For a more comprehensive overview of Paralympic anti-doping rules and regulations, the reader is referred to Chapter 9 of the handbook *The Paralympic Athlete* on nutrition and pharmacology (Vanlandewijck and Thompson, 2011).

The discussion here presents the scientific answer to a question raised in 2009 by a wheelchair rugby athlete about the use of sildenafil citrate (Viagra®). The question was: "Coach, I have been told that the World Anti-Doping Agency (WADA) is considering putting Viagra on the list of forbidden products. I am using Viagra to facilitate sexual intercourse with my wife. As an elite athlete, I am responsible to submit whereabouts information, which allows being located for out-of-competition testing 365 days a year. Could you please inform me about the current status of this matter and advise me on how to handle this situation?" Based on the request of the coach of the Belgian rugby team, the University of Leuven (Belgium) started a systematic literature review on the impact of sildenafil citrate on peak-exercise capacity and exercise performance (continuous effort over a longer period of time at high submaximal level such as the Time Trial performance) in the able-bodied and individuals with spinal cord injury (see Table 9.10).

Sildenafil citrate, a selective inhibitor of phosphodiesterase type 5, induces pulmonary vasodilation. Studies disagree about its impact on exercise capacity in healthy athletes. Only two studies conducted at extreme altitude (Ghofrani *et al*., 2004; Richalet *et al*., 2005) showed an increase in peak exercise capacity. The only two studies examining exercise performance in able-bodied athletes did not reach unanimous conclusions (Hsu *et al*., 2006; Kressler *et al*., 2011).

The athlete's question in combination with WADA's interest in considering sildenafil for further investigation, as well as the lack of absolute data on the impact of sildenafil citrate on exercise capacity and performance in the spinal cord injured, prompted the University of Leuven to initiate a double-blinded randomized controlled trial in collaboration with the Paraplegiker-Zentrum in Nottwil (Switzerland) to investigate this issue. Twenty-seven healthy male wheelchair athletes with a motor-complete spinal cord injury performed
Table 9.11  Peak power output ($P_{\text{O}_{\text{peak}}}^\text{peak}$), oxygen saturation ($\text{SaO}_2$), peak oxygen uptake ($\text{VO}_{2\text{peak}}$), peak heart rate ($\text{HR}_{\text{peak}}$), rating of perceived exertion (RPE), and lactate concentrations (Lac) at cessation of the incremental arm-cranking exercise test after sildenafil and placebo ingestion at sea level (SL) and moderate altitude (MA). Data are presented as median (minimum; maximum).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sildenafil SL</th>
<th>Placebo SL</th>
<th>Sildenafil MA</th>
<th>Placebo MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{O}_{\text{peak}}}^\text{peak}$ [W]</td>
<td>115 (35; 170)#</td>
<td>120 (35; 170)</td>
<td>115 (40; 165)#</td>
<td>115 (35; 175)#</td>
</tr>
<tr>
<td>$\text{SaO}_2$[%]</td>
<td>98 (81; 100)</td>
<td>98 (84; 100)</td>
<td>94 (85; 100)#+</td>
<td>94 (83; 100)+</td>
</tr>
<tr>
<td>$\text{VO}_{2\text{peak}}$ [ml/min/kg]</td>
<td>26 (11; 46)</td>
<td>28 (13; 40)</td>
<td>26 (14; 47)</td>
<td>27 (13; 42)</td>
</tr>
<tr>
<td>$\text{HR}_{\text{peak}}$ [min$^{-1}$]</td>
<td>174 (91; 192)</td>
<td>174 (99; 193)</td>
<td>172 (105; 188)</td>
<td>173 (95; 193)</td>
</tr>
<tr>
<td>RPE</td>
<td>18 (14; 20)</td>
<td>18 (14; 20)</td>
<td>18 (13; 20)</td>
<td>18 (14; 20)</td>
</tr>
<tr>
<td>Lac [mmol/l]</td>
<td>7.5 (1.4; 10.8)</td>
<td>6.3 (1.4; 12.7)</td>
<td>7.3 (1.9; 13.8)</td>
<td>6.2 (2.0; 17.0)</td>
</tr>
</tbody>
</table>

#: significantly different to Placebo SL; +: significantly different to Sildenafil SL.

The ingestion of 50 mg sildenafil citrate or placebo (see Table 9.11). Statistical analysis showed that peak power output at sea level was found to be significantly higher ($p = 0.004$) under placebo treatment (median [min; max] 120W [35; 170]) compared to sildenafil (115W [40; 165]). Blood oxygen saturation under sildenafil treatment at sea level (98% [81;100]) was significantly higher ($p = 0.006$) compared to sildenafil treatment at moderate altitude (94% [85;100]). All other parameters showed no impact of sildenafil or altitude. It was concluded that the ingestion of sildenafil citrate in athletes with spinal cord injury had no positive effects on peak arm-cranking exercise capacity compared to placebo, either at sea level or at moderate altitude.

In a parallel study on the impact of sildenafil citrate on exercise performance at Leuven University, 15 male athletes with spinal cord injury (four were wheelchair rugby players) performed four 30-minute time trials after the ingestion of 50 mg sildenafil citrate or placebo at sea level or moderate altitude (2,200 m). Sildenafil citrate had no effect on average power output and therefore exercise performance at sea level and moderate altitude, but significantly diminished oxygen saturation (from 96.1 ± 0.46 to 95.3 ± 0.46%) and increased heart rate (from 139.7 ± 6.3 to 146.3 ± 6.3 beats/minute) and lactate values (from 4.22 ± 0.55 to 4.76 ± 0.53 mmol/L) at moderate altitude in athletes with spinal cord injury. It was concluded that sildenafil citrate does not develop a meaningful improvement in exercise performance for athletes with spinal cord injury.

Paralympic athletes are unique and will always be confronted with challenges and questions. This example has shown how science can contribute to answering these questions, starting from the available knowledge in able-bodied sports and initiating research studies directly applicable to the Paralympic athlete.

Wheelchair rugby medical assessment

Medical supervision of the wheelchair rugby athlete is of the highest priority because of the complexity of the consequences of the health disorder (i.e., tetraplegia) and the extreme intensity of this contact sport. This complexity too often results in illness and/or injury. For a comprehensive overview of medicine in Paralympic sport, the reader is referred to Chapter 4. This section is a narrative of the medical history of the Belgian wheelchair rugby team, based on the experience of the Belgian team physician and interviews with the athletes.

The incidence of injuries reported during the London 2012 Paralympic Games via the Web-based Injury and Illness Surveillance System (WEB-IISS) is expressed as injuries/exposure, exposure equaling every day an athlete is exposed to injury through training or competition (Willick et al., 2013). Wheelchair rugby ranked 5th in total injuries registered, with 16.3 IR (injury rate per 1,000 athlete-days), which was higher compared to the overall injury rate for all Paralympic Summer sports (IR = 12.7). Percentages of injuries per region per sport
are not yet available, but because of the nature of the game it would not be surprising if wheelchair rugby contributed highly to the overall London 2012 percentage rates of injuries per region: shoulder (17.7%), wrist and hand (11.4%), and elbow (8.8%). From all wheelchair rugby injuries reported, 61% were acute (i.e., any injury caused by a precipitating traumatic event), 22% acute on chronic (an acute injury in an athlete with prior symptoms of a chronic injury in the same anatomical area), and 17% chronic (overuse) injuries (i.e., an injury that developed over days, weeks, or months and was not associated with an acute precipitating event). As many wheelchair rugby athletes use a standardized and personalized treatment regimen for chronic injuries, without interference of the team physician, they would not be identified by the WEB-ISS system. Therefore, the data reported on chronic injuries from the London 2012 survey could be an underestimation of the real number of injuries. Furthermore, no data have been published yet about the causal mechanisms of the injuries reported and observed.

The injury history of the Belgian wheelchair rugby players is what we might expect in athletes with spinal cord injury: shoulder overuse lesions are the main complaint in all players. The shoulder is indeed the engine of wheelchair propulsion, not the elbow or wrist joint. Significant higher shoulder joint torques compared to the elbow joint were already reported in the 1990s (Veeger et al., 1993). This is mainly due to the position of the shoulder relative to the handrim, which brings the elbow into a compromised functional situation: first flexion of the elbow combined with friction generation, then isometric flexion for continued friction, combined with co-contraction between flexors and extensors (if the triceps is available), then extension in an unfavorable angle toward the handrim (if the triceps is available). Most of the overload is expected in the shoulder, resulting in overuse injuries, which require continuous medical and paramedical supervision. The most frequent disabling symptoms mentioned by the athletes are shoulder pain, muscular distress and strain, and myofascial trigger points in the scapula region. Also, the deltoid becomes a muscle of concern sooner or later.

Moreover, straightforward propulsion is only one of the key activities in wheelchair rugby. Because of the repetitive blocking, picking, and holding activities, the elbow joint torques will also probably be very high, resulting in biceps tendinitis and triceps overuse with pain and functional complaints during competition periods. However, elbow joint torques during repetitive starting and stopping the wheelchair, turning and countering, forcing the opponent into a locked position, have not been measured or simulated.

Overuse injuries of shoulders and elbows have dominated the medical records of the Belgian wheelchair rugby squad. Wrist overuse was a less important problem that could be avoided by taping. The fact that the Belgian team has always been small in comparison to other teams has been a huge disadvantage in their career. The Belgian team entered the international scene in 1996 with only six players (see Figure 9.2). In the past 20 years, only 22 athletes started playing wheelchair rugby in Belgium and made it to the team. Top teams in the world can put at least two, sometimes three equivalent line-ups on the court. The international success of the Belgian wheelchair rugby team is a combination of superb physical condition, each individual player demonstrating athletic identity, tactical intellect, but above all boundless energy and devotion. Yet the price could be a medical one: some players are being fielded for almost four
full quarters during an entire international tournament. While the opponent was rotating, the same Belgian line-up had to continue to keep the pressure on to stay in the game. On top of the excessive field time, the lack of sport-specific medical policy in the inaugural years of the team was undeniable. Fortunately, more and more knowledge about orthopedic issues in the spinal cord–injured population has been gained, and this knowledge is being transferred more efficiently and systematically through Team Physician Workshops organized by the International Paralympic Committee.

While shoulder and elbow overuse injuries kept athletes off the court, pressure ulcers should have kept them from playing. The decision not to give permission to train and play is often contested because of the absence of pain. Players knew that such a decision could keep them from playing for months, until the pressure sore was completely healed. The player’s resistance against such a medical decision was anticipated through consulting two physicians. Fortunately, prevention and early treatment of pressure ulcers are more scientifically substantiated.

Coach’s Corner

Minor lesions such as bruises, finger fractures, and lacerations are a concern for the team physician; because of the absence of pain, such lesions will not keep a wheelchair rugby player from performing. Pain of which athletes are not aware during training or game performance can become relevant in activities of daily living, such as making a transfer to another wheelchair after the game. Coaches should always be informed about physical complaints experienced on and off the court.

In London 2012, more than 20% of the Paralympian wheelchair rugby players were affected by illness during the total screening period (3 days pre-Games and 11 days during the Games; Swellnus et al., 2013). However, the incidence rate of 10.8 was average compared to the minimum IR of 2.2 for football 7-a-side and the maximum 20.7 for equestrian. Unfortunately, for wheelchair rugby no breakdown was done of common affected systems. The totals for IR/system were respiratory (3.93), skin (2.71), digestive (1.96), nervous (1.78), genitourinary (1.68), and ears/mastoid (1.12). For more details, the reader is referred to Chapter 4.

Coach’s Corner

Wheelchair rugby players should take their morning temperature first thing after waking up. In principle, the temperature will be constant; a sudden but persistent slight elevation of the morning temperature is often a precursor of impending illness.

Wheelchair rugby athletes experiencing urinary incontinence, managing this situation through catheterization, might be confronted with a dilemma during competition. Waiting to empty the bladder can make blood pressure rise, causing autonomic dysreflexia; as a consequence, performance capacity will also rise, but having wet pants is embarrassing. Headache due to autonomic dysreflexia is not a condition in which to stay on the field during a competition. More often the concern is prior to the possible advantage: not drinking and risking dehydration is more frequent than the intention of exploring the thin line between what can be accepted and what is forbidden. There is no athlete who wants to miss a sublime moment in the game because of an intermittent catheterization.

Athlete monitoring systems

In Chapter 8, the reader is introduced to time–motion analysis, a screening method using video cameras or a Global Positioning System (GPS) to track the movement patterns and calculate the workload of athletes through assessing the total distance covered, total time in discrete activities, distances traveled within velocity bands, as well as frequency of activities during training or match play. Because of the low sampling frequency of video and GPS, time–motion analysis has been combined with accelerometry to get a more accurate estimate of the physiological demands of the players’ efforts. The full potential of this athlete monitoring system is yet to be fully explored, especially from an injury-prevention perspective. Basing assumptions regarding physical fitness and
fatigue purely on activity profile statistics is flawed, particularly given that our understanding of physiological responses during match activity remains limited. For example, it is still unknown to what extent the dynamic responses to match demands (such as accumulation of metabolites in muscles, plasma osmolality, substrate availability, body temperature, and dehydration) prevent the total breakdown of any single peripheral physiological system, either prematurely or in the final periods of the match (Mohr et al., 2005).

In recent years, the use of time–motion analysis was also introduced in wheelchair rugby (Sarro et al., 2010; Mason et al., 2014; Rhodes et al., 2015a, 2015b). It is a sport where players perform bouts of high-intensity activity interspersed with periods of lower intensity. The demands are increased by having to execute complex movements such as accelerating and decelerating, changing direction, tackling, blocking, and holding; to do this, players need an appropriate level of fitness, namely moderate-to-high aerobic and anaerobic power, good agility, flexibility, and muscular development, as well as the ability to generate power during fast movements. Given the demanding nature of wheelchair rugby, players will likely experience a degree of transient or accumulated fatigue at some stage of the match. A significant decline in match-play activities observed by Sarro et al. (2010) was not confirmed by Rhodes et al. (2015b), suggesting that match-play activity was not influenced by fatigue as in the latter study.

### Coach's Corner

Coaches should work closely together with the team physician and the sport scientist to control the workload of players during training and competition, and match these data with the actual athlete’s perception and individual injury register.

The use of GPS/accelerometers, combined with physiological values (e.g., rating of perceived exertion [RPE], heart rate, lactate) and other data such as perceived muscle soreness, fatigue, mood, and sleep ratings, may provide additional insight into the training load–injury risk relationship of elite wheelchair rugby players.

### Wheelchair rugby classification

For a more comprehensive and general overview of the process of evidence-based classification research, the reader is referred to Chapter 7. In wheelchair rugby classification, the objective is to minimize the impact of impairment on wheelchair rugby–specific performance; over the last couple of years, enormous progress has been made in developing this evidence-based system. In 2010, an expert group of classifiers and athlete representatives proposed a revised trunk impairment classification (TIC) system, with a maximum of 10 tests arranged in an algorithm leading to allocation of a trunk score (0, 0.5, 1.0, or 1.5) after failure of one or more tests. This proposed revision was adopted by the International Wheelchair Rugby Federation later that year (www.iwrf.com). The TIC is a health disorder–independent test and results in a composite score for trunk strength, trunk active range of motion, and trunk coordination. It is a non-instrumented test and is easy to administer by a team of two classifiers (Altmann et al., 2013). Table 9.12 shows that wheelchair rugby and wheelchair basketball players with TIC scores of 0.5, 1.0, and 1.5 demonstrate a significantly different active range of motion of the trunk in one oblique direction, with a tendency for differences in all directions. In Table 9.13, athletes with TIC scores of 0, 0.5, 1.0, and 1.5 clearly demonstrate differences in isometric trunk strength in all directions. These results show the content validity of the TIC.

To demonstrate the impairment–performance relationship, athletes with different TIC scores were asked to perform core wheelchair rugby activities, such as acceleration from a standstill, 20-meter sprint, tilting one wheel of the wheelchair, and hitting. The approach of Altmann et al. (2013) can be categorized as process-focused research, which is the way to go to develop evidence-based classification systems (Tweedy and Vanlandewijck, 2011).

Many studies dealing with wheelchair rugby and referring to the classification system can be categorized as product-focused research. It is unknown whether the classes are a good representation of the
Table 9.12  Range in the dynamic sitting balance task per trunk score Reproduced with permission of Viola Altmann.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Trunk score</th>
<th>Kruskal-Wallis test (H)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>n</td>
<td>7</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Range AP</td>
<td>237</td>
<td>272</td>
<td>315</td>
</tr>
<tr>
<td></td>
<td>(84–330)</td>
<td>(213–331)</td>
<td>(236–337)</td>
</tr>
<tr>
<td>Range LR</td>
<td>183</td>
<td>200</td>
<td>229</td>
</tr>
<tr>
<td></td>
<td>(111–261)</td>
<td>(120–228)</td>
<td>(198–257)</td>
</tr>
<tr>
<td>Range LOF–ROB</td>
<td>179</td>
<td>205</td>
<td>291</td>
</tr>
<tr>
<td></td>
<td>(105–303)</td>
<td>(177–283)</td>
<td>(250–336)</td>
</tr>
<tr>
<td>Range ROF–LOB</td>
<td>208</td>
<td>243</td>
<td>280</td>
</tr>
<tr>
<td></td>
<td>(108–322)</td>
<td>(186–313)</td>
<td>(251–316)</td>
</tr>
</tbody>
</table>

* = significant for TIC 0.5–1.5 and TIC 1.0–1.5 in post hoc testing.

n = number of athletes who performed the test.

Range AP = range in anterior–posterior direction; median in mm (range in mm).

Range LR = range in left–right direction; median in mm (range in mm).

Range LOF–ROB = range in left oblique forward–right oblique backward direction; median in mm (range in mm).

Range ROF–LOB = range in right oblique forward–left oblique backward direction; median in mm (range in mm).

different wheelchair rugby player classification profiles, differentiated by the impact of impairment on performance. In these studies, classes are often grouped together to increase the statistical power, with wheelchair rugby studies frequently composed of four groups: group I = 0.5 players; group II = 1.0 and 1.5 players; group III = 2.0 and 2.5 players; and group IV = 3.0 and 3.5 players. Comparable to wheelchair basketball, wheelchair rugby player profiles are described in detail for the extreme classes of the continuum and the full-point classes (i.e., 0.5, 1.0, 2.0, 3.0, and 3.5 players). The half-point players 1.5 and 2.5 are considered borderline cases, demonstrating characteristics not 100% compatible with either of the adjacent classes, and therefore should not be amalgamated in a comparison between classes.

Wheelchair rugby classification is struggling with the fact that the classes are now ratio scaled. This implies that the impact of impairment on the performance of a 0.5 player is three times as important as for a 1.5 player and seven times as important as for a 3.5 player. This is not at all in agreement with some core wheelchair rugby performance

Table 9.13  Isometric trunk muscle strength in all directions per trunk score. Reproduced with permission of Viola Altmann.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Trunk score</th>
<th>p-value Kruskal-Wallis test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>n</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Right</td>
<td>77.97 (36.62–191.78)</td>
<td>188.94 (91.67–279.16)</td>
</tr>
<tr>
<td>Left</td>
<td>92.92 (44.78–148.54)</td>
<td>184.78 (64.56–279.16)</td>
</tr>
<tr>
<td>Forward</td>
<td>87.78 (38.63–160.26)</td>
<td>257.68 (155.47–326.84)</td>
</tr>
<tr>
<td>Backward</td>
<td>93.32 (38.63–291.85)</td>
<td>342.90 (178.80–555.66)</td>
</tr>
<tr>
<td>Backward foot</td>
<td>92.30 (56.00–178.52)</td>
<td>405.63 (200.85–704.42)</td>
</tr>
</tbody>
</table>

n = number of athletes that performed the test.

Right = median trunk muscle force when pulling to the right in Newton (range in Newton).

Left = median trunk muscle force when pulling to the left in Newton (range in Newton).

Forward = median trunk muscle force when pulling in flexion in Newton (range in Newton).

Backward = median trunk muscle force when pulling in extension in Newton (range in Newton).

Backward foot = median trunk muscle force when pulling in extension in Newton with the feet supported on the floor (range in Newton).

* = significant at p < 0.05.
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characteristics (e.g., Class 0.5: \( V_{\text{peak}} = \pm 2.5 \text{ m/s} \); Class 1.5: \( V_{\text{peak}} = \pm 4.2 \text{ m/s} \); Class 3.5 = \( V_{\text{peak}} = \pm 4.4 \text{ m/s} \)). To protect the 0.5 player from being excluded from the line-up, the 0.5 Class could be revised or the ratio scale with the 8.0 rule, which is the maximum classification of a line-up, could be abandoned.

In their devotion to contributing to the development of a fair and equitable classification system for athletes with spinal cord injury, some authors have advocated the incorporation of autonomic testing in the classification of wheelchair rugby players (Mills and Krassioukov, 2011). However, impaired cardiovascular control is not one of the ten impairment types that are eligible for Paralympic sport. This issue is more extensively addressed in Chapter 7 under the discussion Step 1: Identify target sport and impairment types to be classified.

Conclusion

Athletes are individuals with their own mind, character, ambitions, dreams, and a body that reacts in a very specific way to exercise. Even though the discussion of wheelchair rugby has proven that the wheelchair rugby athlete’s body is complex, it is the challenge for every coach to align individuals into a powerful team. Coaches should have the time to do exactly this: build a team. In most countries, on a national level, wheelchair rugby athletes train two to three times a week with all players of the team present. As a training session has an average duration of approximately two hours, the coach has four to six hours per week to reach his or her goals. This is the time to develop team goals, team tactics, team culture, and team spirit; this includes, in addition to the on-court training, off-court team-building activities and team meetings involving the entire team staff. If a coach has only a couple of hours per week to build the team, it is the responsibility of each individual athlete to appear at team training in the best shape possible. Individualized training programs developed by the coach and physical trainer (often one and the same person) become the responsibility of the athlete. This includes preparation for the new season: athletes should arrive at the first team training in good physical condition, well recovered from the past season, and ready to prepare for the new season as a team.

Individual training is a cornerstone to team success. The Belgian wheelchair rugby team has demonstrated an exceptional work ethic over their whole career. Most of the players used handcycling for physical conditioning in the off-season and non-team-training days, augmenting the total training frequency to five to six days per week, respecting at least one recovery day per week without any training. Handcycling may have had a compensating impact on the imbalanced shoulder musculature caused by wheelchair rugby–specific training and perhaps prolonged the athletes’ career. On the other hand, in their search for physical primacy, recovery is the word that athletes hate the most. Where some coaches need to motivate and stimulate, the Belgian wheelchair rugby coach’s major challenge was to guarantee recovery.

Handcycling is a good complement to dynamic wheelchair sports in the off-season. In addition to the compensatory mechanisms for shoulder muscle imbalance, it provides an excellent training method to build an aerobic platform as a basis for an aerobic–anaerobic wheelchair rugby season. Furthermore, handcycling at low intensity is also ideal for recovery training the day after the game or intensive interval training. A physical trainer should always try to challenge and balance the athlete’s whole body, within and outside the

Coach’s Corner

Individualization is a key word in wheelchair rugby physical conditioning. The physiological reaction to exercise in athletes with cervical spinal cord lesions is still not very well understood. In the study by Valent et al. (2007), only 8 out of 18 participants demonstrated a linear HR–\( \text{VO}_2 \) (maximal oxygen consumption) relationship. The authors concluded that an individual analysis of the HR–\( \text{VO}_2 \) relationship is necessary to determine whether HR can be used to quantify exercise intensity. Furthermore, West et al. (2013) demonstrated in 7 elite wheelchair rugby players that the heart rate limitations of athletes with complete cervical spinal cord lesions can exceed the \( \pm 130 \text{B/min} \) reported in the literature. West et al. (2013) measured average \( HR_{\text{peak}} \) of 152 \( \pm 20 \text{B/min} \) in a field test. The same group of athletes recorded a significant lower \( HR_{\text{peak}} \) in an incremental arm-cranking test to exhaustion (123 \( \pm 13 \text{B/min} \)).
sport-specific environment. Complementary training sessions outside the rugby chair are not very welcomed by the athletes. However, the wheelchair serves as a harness (the rugby chair even more than the activity-of-daily-living chair), supporting and balancing the body, but decreasing the need for active core stability control. Therefore, training sessions outside of the wheelchair in a safe environment, once every two weeks in the off-season, will complement the wheelchair rugby–specific training.

Coach’s Corner

Comment of a wheelchair rugby athlete before a swim training:
“Coach, we are wheelchair rugby players, not fish.”
Comment after the swim training: “Today I used muscles I wasn’t aware of having.”

Another complement to wheelchair rugby–specific training might be inspiratory muscle training. In a randomized controlled trial, West et al. (2014c) investigated the impact of inspiratory muscle training in 12 elite wheelchair rugby players on exercise responses to maximal arm cranking. A strong trend with a large observed effect toward an increase in peak power output and VO$_{2peak}$ was noted; it was proposed that inspiratory muscle training may provide a useful adjunct to regular exercise training in the elite wheelchair rugby player with tetraplegia. For more detailed information on respiratory training to improve exercise capacity and the performance of wheelchair rugby athletes, the reader is referred to Chapter 3. Regarding alternative respiratory muscle training (i.e., isocapnic hyperpnoea training), the Belgian wheelchair rugby players were not standing in line to participate in this kind of non-rugby-specific training. However, respiratory muscle training is recommended, especially for athletes with the highest cervical lesion levels; that is, Class 0.5 and 1.0 players.

Of course, this chapter has not addressed all the perspectives of training and coaching of the wheelchair rugby athlete. For sport psychological guidance and mental training, the reader is referred to Chapter 5. With respect to tactical training, not too much work has been done from a sport science perspective. Nevertheless, an athlete’s sports-related perceptual-cognitive abilities (i.e., the ability to process complex dynamic wheelchair rugby scenes) could be assessed and trained though a multiple object tracking system. It has been demonstrated that professional soccer, ice hockey, and rugby players have extraordinary skills for rapidly learning unpredictable, complex dynamic visual scenes (Faubert, 2013). How athletes handle the complex dynamic visual wheelchair rugby environment is still virgin scientific territory.

Acknowledgments

The author would like to thank all who contributed to the success of Belgian wheelchair rugby in the past 20 years. I would like to express my great appreciation to the Elite Sports Bureau of Parantee (formerly the Flemish League for Disability Sport) and its members, Annick Viaene (Sport Medicine), Els Snauwaerts (Sport Psychology), Steven Van Beylen (sports coordinator Parantee), Tim Decleir (sport manager wheelchair rugby), and Joeri Verellen (sport scientist). I also would like to thank Peter Van de Vliet, who succeeded me as physical trainer from 1997 to 2006. Viola Altmann should be acknowledged for bringing the evidence-based wheelchair rugby classification system a significant step forward.

To close this chapter, I would like to thank the Belgian wheelchair rugby squad for the enormous sporting pleasure and excitement that they bring to the court. Every coach should once in his or her career experience the luxury of working with a young, talented group of athletes with the utmost devotion and work ethic toward their sport. On and off the court, these athletes were and are true examples of elitism in sport – true Paralympians. It is an honor and pleasure to be a small part of their incredible journey.

References


Introduction

Athletes can utilize and apply sport science during their individual daily training sessions, their higher-level periodized season plans, and within elite competition. In each of these scenarios the coach draws on the knowledge in the “sport science toolbox” to guide and make an informed decision on how to best optimize swimming performance. The science of swimming is the combination of established scientific principles within the sport of swimming. These scientific principles are typically established and validated with an able-bodied swimming population, then modified (if necessary) to match the unique requirements of the Paralympic athlete. In all cases, scientific principles form the backbone in measuring what is happening within the sport, and once documented this benchmark can influence the strategic decisions that the coach and support staff make.

Since the process is multi-disciplinary, the organization of this chapter reflects that profile. In some cases the guidelines set forth are the same regardless of the group of swimmers being considered, for example the fundamental principles underlying propulsion and drag are the same for able-bodied and Paralympic swimmers alike. In others there are marked differences. A swimmer who has a spinal cord injury and spastic muscles, for example, may develop a “fixed-hip” contracture, so will have to adopt different techniques to maximize performance. The key message when applying sport science to any sport is that there is no general model for all athletes and all conditions, but rather established scientific laws and principles that can be applied to optimize the unique athlete for a specific swimming event.

The science of swimming: Background

In comparison to Olympic or able-bodied swimming, Paralympic swimming has a shorter history of competition, and subsequently a smaller window for development and application. The first modern Olympic Games were held in 1896 to provide competition for sportsmen, whereas Paralympic sports evolved from rehabilitation programs in the 1940s (see Chapter 1), and as such were built on medical scientific knowledge with an application to exercise. These programs initially focused on spinal cord-injured athletes. The competitive sports program became an extension of the rehabilitation program for these patients. Many of the pioneers in disability sports were medical doctors, particularly in cases where these programs grew out of the rehabilitation institutions.

The first known international swimming sport science research project was conducted at the 1988 Seoul Olympic Games. This sports science project...
analyzed the swimming race and measured determinant factors such as start time, stroke rate, stroke length, distance per stroke, turn time, finish time, and swimming velocity within each 25-meter race segment (Chengalur and Brown, 1992). Four years later at the 1992 Barcelona Paralympic Games, the first international Paralympic swimming race analysis was conducted (Arellano et al., 1994). Although different research teams were involved, the swimming race analysis continued at the 1996 Atlanta Olympic and Paralympic Games (Daly et al., 2001) and at the 2000 Sydney Olympic and Paralympic Games, where exactly the same analysis was conducted for Olympic and Paralympic swimmers (Daly et al., 2003). Unfortunately, in the following games in Athens 2004 and Beijing 2008, there was no international swimming analysis, but data were collected at the London 2012 Games that are yet to be published.

Many coaches, athletes, and scientists take the knowledge and experience from Olympic performances and apply it (sometimes with modification) to Paralympic sport. For example, when designing the training program for a Paralympic swimmer, the coach and sport scientist could use the Olympic swimmer’s training routine as the starting point. As with any sport science analysis, the adaptation process of the athlete is carefully monitored, as this knowledge transfer will enable the strategy for performance enhancement to be developed. From these valuable scientific data, the coach can be equipped to make informed decisions on the Paralympic swimmer’s training program.

As with Olympic sports, the Paralympic Games have experienced an increase in the number of official sport scientists as part of each country’s Paralympic team. From the valuable data collected by these researchers, the coach and athlete are able to evaluate swimming performance and determine how to enhance it for future events, such as the final race of the competition. This new knowledge can help to identify which components to work on in the athlete’s training, such as stroke count, swim pace, race strategy, aerobic fitness, and maximum speed work. Working together, the coach, athlete, and sports scientist can have a positive impact on the athlete’s sport performance.

The science of swimming: Fundamentals

The decisions made on how to train and coach the Paralympic athlete begin with comprehending the fundamentals of sport science. Specifically for swimming, this involves understanding propulsion and drag within the water, swimming physiology, mood state and visualization, and how to prevent injury.

The training program needs to stimulate and improve the performance of the athlete to match the variability of swimming performance within and between national and international competitions. In an Olympic year, potential Olympic medal swimmers need to improve their motor skill performance by \( \sim 1\% \) within competitions, and \( \sim 1\% \) within the year leading up to the Olympics, to keep pace with the competition and give themselves a chance to reach the podium (Pyne et al., 2004). Athletes who are able to obtain an additional enhancement, even one as low as \( \sim 0.4\% \) between competitions, can substantially increase their chance of winning a medal.

Understanding propulsion and drag

The same principles of propulsion and drag apply to all swimmers, regardless of ability level, and these principles influence the technique used to achieve optimal performance. One of the fundamentals in
swimming is that for one to swim faster it is necessary to increase propulsion, decrease drag, or a combination of both. When analyzing the swimming mechanics for Paralympic swimmers, there may be some variations to how these net forces are generated. Swimmers with an amputation, cerebral palsy, or spinal cord injury may utilize different movement patterns due to their impairments; however, the same underlying mechanical principles apply. For example, a swimmer who is a single-leg amputee will have a smaller base of support on the blocks, affecting his or her ability to achieve balance during the start. The natural compensations that the swimmer makes on the blocks can subsequently lead to asymmetry on entering the water, which in turn can lead to altered swimming mechanics underwater and when stroking (e.g., altered inter-arm stroke coordination).

**Swimming physiology**

To design the training session, the Paralympic athlete and coach often seek advice from the exercise physiologist to determine the appropriate intensity and duration for training. The most common measures taken during a training session are heart rate and blood lactate. The measurement of lactate production after racing events and during recovery is a practice within many swimming programs, as this variable can be related to swimming performance and effective recovery. The predominant energy system used in swimming during sprinting events is the anaerobic system. This is due to the short duration of these events and the muscle fiber types principally used. Blood lactate is a good measure of anaerobic performance.

Established relationships currently exist between heart rate, blood lactate, and the training intensity, or training zone. Using this knowledge, the coach and athlete have a scientific measure of whether their training will result in the desired performance outcome. A commonly accepted sport science measure to quantify aerobic capacity in swimmers is to use an incremental test set of $7 \times 200$-meter swims on a descending time of 5 seconds quicker. A micro blood sample can be taken and the lactate level measured after each 200-meter swim. This swim will enable the relationship between lactate, swimming speed, and lactate tolerance (ability to remove lactate from the blood at specific intensities) to be quantified. An example is shown in Figure 10.1 (see also Pyne et al., 2001).

**Mood state and visualization**

As with Olympic athletes, the Paralympian is confronted with similar issues of the psychological effects of exercise, the problem of exercise adherence, motivation, and the anxiety experienced pre-competition as well as in the middle of a major event. The established process of proactively controlling the athlete’s mood state, visualization, and

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**Coach’s Corner**

Despite competing in an aquatic environment, it is challenging for the Paralympic swimmer to accommodate thermal regulation. For example, an athlete with a spinal cord injury tends to have a reduced lower-limb surface area due to the associated muscular atrophy, and being wet from the water can “mask” sweating and thermal regulation. A similar scenario exists for the amputee who has lost part or all of a limb. This different surface area will naturally influence thermal regulation. Furthermore, the modified neuromuscular system for some athletes with cerebral palsy has resulted in heightening their sensitivity to hot and cold climates. The take-home message is to keep drinking fluids (despite being in the water) and at the other end of the spectrum to be aware of colder than normal pool temperatures, which can cause involuntary muscle contractions.

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**Figure 10.1** Representation of a typical lactate-velocity curve showing the derivation of the lactate tolerance rating (LT5–10) and the LT. **Source:** Pyne 2001. Reproduced with permission of American College of Sports Medicine.
pre-competition thought process is of particular importance to the outcome of the sporting performance. In most cases, the Paralympic athlete can apply similar visualization processes as the Olympic athlete, but for some disabilities this is not possible. In using visualization techniques, athletes often will watch a video of a past performance, usually their best performance, so as to “visualize” the perfect race. For athletes with a visual impairment or blindness this is not possible, so they need to resort to other techniques such as hearing or to rely on their confidence in a predefined race strategy.

Among swimmers with cerebral palsy, there are a very small number who may also have an intellectual impairment. This could restrict their ability to use the power of the mind to modify mood state, to concentrate, or to follow the race plan. Likewise, when employing muscle relaxation techniques to bring the athlete into the desired mood state, the process of systematically contracting and relaxing muscle groups within the body to create an overall level of relaxation may need to be modified for the athlete with an amputation. In the case of the athlete who has lost a limb or has a spinal cord injury, there may be limited or no ability to systematically contract and relax muscle groups.

The athlete who has an intellectual impairment may have a different response mechanism to the “burn-out” or “staleness” that is common in athletes following long periods of training and competition. Sport science has contributed to developing novel mechanisms to address these issues, such as incorporating other sensor cues of smell and a more detailed description of the environment or mood state. Some of these are discussed in more detail in Chapter 5.

**Application to prevent injury**

Paralympic swimmers who have a visual or intellectual impairment or mild cerebral palsy will generally experience similar levels of injuries associated with swimming to an able-bodied athlete, the most common of which is swimmer’s shoulder. Prevention follows the same principles to ensure that the athlete’s musculoskeletal system is suitably flexible and stable, along with appropriate swimming technique.

For swimmers with cerebral palsy, amputation, or spinal cord injury, the loss of function within one region can result in overload and compensation, resulting in an increase in injury potential. The key to avoiding these issues follows the same principles for any swimmer: to insure that the swimmer’s musculoskeletal system is as symmetrical as possible and that the swimmer has a safe but effective swimming technique. Of particular interest are swimmers with spinal cord injury, who rely on their wheelchair for mobility, and here two key factors need to be considered when trying to avoid injury. First, avoid overloading the shoulder, as the athlete typically relies on the shoulder to propel the wheelchair (in the event of a shoulder injury, daily mobility will subsequently be impaired). This issue can be addressed by careful monitoring of the swimmer’s internal and external range of shoulder movement using a regular sport science screening measure (Evershed et al., 2014). This will enable valuable feedback on the intensity levels of both the in-water and dry-land training regimens. A key finding from the science of swimming is to develop symmetry around the shoulder, which may require working on compensatory exercises to reduce asymmetry. Correct sport science assessments can avoid potential shoulder injury issues. Unfortunately, the second issue can be more challenging to address.

A swimmer may spend the majority of the day in a wheelchair, coupled with the fact that there is a low level of stimulation to the lower limbs, and athletes can develop fixed contracture at the hips. The muscles can shorten, resulting in semi-permanent flexion of the hip joint, potentially reaching 90° of flexion. In freestyle, breaststroke, and butterfly swimming strokes, fixed hip contracture can create an excessive frontal drag profile and significantly affect the swimmer. In the backstroke position, the upright fixed hip position will exaggerate body roll and further challenge the limited (or lack of) abdominal control that most athletes in this situation experience.

Equipment such as prostheses and wheelchairs is fundamental, allowing some people with disabilities to carry out the tasks of daily living. Lower-limb amputees rely on the technical attributes of their prosthetic limbs to ambulate, and the
One option to overcome the fixed contractures is to combine the buoyancy of water and some additional swimming training aids to stimulate the musculoskeletal system. For example, even though the swimmer may have reduced or total loss of function and stimulation in their lower limbs, swimming with a set of flippers (or swimfins) could provide an active level of movement in the affected limb(s). Furthermore, when applied in water the use of flippers or hand paddles can create an additional amount of loading to the specific joint, which can also help build strength in the swimmer.

Specifications of these components have varied considerably in recent years. Of the greatest importance are the not-so-obvious compensatory factors that come with using prostheses, which can detrimentally influence the swimmer. Often the result of an amputation or spinal cord injury can create asymmetry within the human body and this can naturally influence how the athlete will ultimately swim. These are discussed in more detail in the following sections on propulsion and drag, application to prevent injury, and in some of the Coach’s Corner boxes.

**Components of the swimming race**

Competition or swimming race analysis has become a regular feature at most international swimming events since 1988, when official videos were first recorded above the water during the Olympic Games. Variables that are commonly filmed and measured include start, turn, and finish times, as well as 25-meter and 50-meter lap split times. The swimmer’s race pattern is defined by the within-race changes in stroke parameters and resultant changes in swimming speed.

Within several countries (UK, USA, Australia, Germany, Belgium, Canada, France, and Brazil) sport science research has compared the swim start of Olympic and Paralympic swimmers over a number of national elite swim training camps. The specific impairments of the Paralympic swimmers enabled the researchers to monitor the influence of some of the variables that contributed to the swimmers’ start. For example, the influence of block time is apparent when analyzing swimmers with cerebral palsy, as their inhibited neural muscle recruitment results in an inefficient kinetic link required to generate a fast block time. When comparing the start time to 15 meters, there was a significant difference between the Olympic and Paralympic classes, with the start time progressively increasing as the Paralympic class decreased (Dingley et al., 2014).

**Starts**

The swim start is defined as the distance to the 15-meter mark in the race, which coincides with the break start rope and is the maximum distance that a swimmer can travel underwater. The same Fédération Internationale de Natation (FINA) start rules apply for Olympic and Paralympic swimmers. The swim start can be divided into a number of subsections, including time components (block, flight, underwater, and free swim) as well as distance components (entry, underwater, and free swim). In several studies of the 200-meter starts, 95% of the variance in start time was attributed to the underwater phase (Burkett et al., 2010), and a greater entry distance had little relationship to the start time ($r = 0.046$).

The swimmer’s start is an important component of the complete swimming race, as it is the section of the race where the swimmer is traveling at the fastest velocity. Typical average velocities for elite male able-bodied swimmers over the first 15 meters of the race are around 3 meters per second, while free swim velocities are of the order of 1.8 meters per second for freestylers. The Paralympic swimmer who has a mild or minimal impairment can also achieve these velocities. It is therefore imperative that swimmers, regardless of ability level, maximize their velocity at the start and continue this velocity for as long as possible into the race.

To better understand the swimming start and considerations to be made for Paralympic swimmers, comparisons between Olympic and Paralympic swimmers have been conducted. In a 2010 study (Burkett et al., 2010), three of the specific Paralympic classifications (swimmers in which could
most closely match an Olympic swimmer) included the following:

- **S8**, where swimmers had full use of their arms and trunk with some leg function (this can include coordination problems), had double limb loss, or only had the use of one arm.
- **S9**, where the swimmers had severe weakness in one leg only, swim with very slight coordination problems, or had one limb loss.
- **S10**, where the swimmers had very minimal weakness affecting the legs, swam with restriction of hip joint movement or with both feet deformed, or had a minor limb loss/loss of part of a limb.

Within these classes, three Paralympic impairment groups were represented: swimmers with an arm amputation (leg-dominant swimmers), swimmers with a leg amputation (arm-dominant swimmers), and swimmers with hemiplegic cerebral palsy (neuromuscular-impaired swimmers). Investigating the different impairments of the Paralympic swimmers enabled the researchers to monitor the influence that some of the variables had on the swimmers’ start. It was hypothesized that the different classes of Paralympic swimmers would execute specific components of the start differently, and this was found to be the case. Some of the key results are highlighted in Table 10.1.

The applied research found that the underwater velocity had the greatest influence on the swim start time, and as such is an area where the S9 and S8 swimmers need to work to improve performance. From analysis of underwater video footage, both of these classes of swimmers tended to have a wider streamline profile, which naturally creates an increased resistance that consequently reduces the underwater velocity. Swimmers with cerebral palsy may require other specific changes, such as interlocking their hands, to avoid the arms drifting apart underwater and having a negative impact on drag when streamlining underwater.

When comparing specific impairments, the swimmers with a leg amputation or cerebral palsy both had shorter underwater distances, although they were not significantly different. Both of these groups of swimmers have a reduced kicking capability due to the loss of a leg or to the involuntary muscle spasms that occur in cerebral palsy, which will interfere with a coordinated leg kicking action. The end result is that the above-water free swimming phase is more efficient when compared to the kicking-dominant underwater phase in these athletes.

Due to the diversity in the physical ability of Paralympic swimmers, the underwater distance traveled will depend on the strength and weakness (underwater streamlining and kicking efficiency) of the individual swimmer, although a key requirement for all groups was the smooth transition from underwater to free swimming. Although there was a difference found in the absolute distance that the swimmers traveled underwater, in relative terms there was no difference between the three Paralympic swimming classes, although the entire group of Paralympic swimmers spent significantly less time underwater. This similar proportion of time and/or distance spent in each phase, regardless of Paralympic class, indicates that the swimmers follow a similar pattern of swim start technique.

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**Coach’s Corner**

The aim for swimmers is a seamless underwater to free swimming velocity transition. It should be emphasized that each athlete may need to be analyzed individually to allow for athlete-specific idiosyncrasies. Most importantly for swimmers and coaches, these components of the start can be modified with training. As with other changes in technique, such as breathing patterns and stroke rates, these elite athletes can apply this new knowledge to help improve their swim start underwater.

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By only considering the class, and not the impairment, some key features of athletic performance are hidden. For example, while there is a significant difference in the absolute start time between the Olympic and all three Paralympic classes (S10, S9, and S8), there is no significant difference in start time between the three disability groups of arm amputee, leg amputee, and cerebral palsy. The block times of the S10 and S9 as well as the arm and leg amputees were similar, while the cerebral palsy and S8 swimmers had a significantly slower block time when compared to all other swim groups. This result highlights the finding that the impaired neuromuscular motor pattern in people with cerebral palsy affects the execution of movement patterns and causes delayed planning of movement.
Table 10.1  The absolute time, distance, and velocity components (mean ± standard deviation) of the swimming start by class and by disability.

<table>
<thead>
<tr>
<th>Olympic and Class variables</th>
<th>Olympic (n = 5)</th>
<th>S10 (n = 5)</th>
<th>S9 (n = 5)</th>
<th>S8 (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start to 15 m</td>
<td>6.24 ± 0.17a</td>
<td>7.32 ± 0.25b</td>
<td>7.83 ± 0.56c</td>
<td>8.31 ± 0.83d</td>
</tr>
<tr>
<td>Block</td>
<td>0.77 ± 0.05a</td>
<td>0.85 ± 0.08b</td>
<td>0.85 ± 0.07b</td>
<td>0.94 ± 0.14d</td>
</tr>
<tr>
<td>Flight</td>
<td>0.60 ± 0.05a</td>
<td>0.42 ± 0.10b</td>
<td>0.51 ± 0.06b</td>
<td>0.30 ± 0.14d</td>
</tr>
<tr>
<td>Underwater</td>
<td>3.39 ± 0.77a</td>
<td>2.45 ± 0.35b</td>
<td>2.54 ± 1.34b</td>
<td>2.10 ± 0.52d</td>
</tr>
<tr>
<td>Free swim</td>
<td>1.35 ± 0.66a</td>
<td>3.33 ± 0.37b</td>
<td>3.73 ± 1.33b</td>
<td>4.33 ± 1.16d</td>
</tr>
<tr>
<td>Distance (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry</td>
<td>3.17 ± 0.48a</td>
<td>2.82 ± 0.39b</td>
<td>2.88 ± 0.28b</td>
<td>2.51 ± 0.28d</td>
</tr>
<tr>
<td>Underwater</td>
<td>8.87 ± 0.66a</td>
<td>6.23 ± 1.07b</td>
<td>5.96 ± 2.04b</td>
<td>5.14 ± 1.53d</td>
</tr>
<tr>
<td>Free swim</td>
<td>2.96 ± 1.07a</td>
<td>5.87 ± 1.09b</td>
<td>6.07 ± 2.20b</td>
<td>7.38 ± 1.89d</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underwater</td>
<td>2.69 ± 0.42a</td>
<td>2.37 ± 0.23a</td>
<td>1.91 ± 0.08b</td>
<td>1.68 ± 0.12d</td>
</tr>
<tr>
<td>Free swim</td>
<td>2.38 ± 0.23a</td>
<td>1.75 ± 0.18a</td>
<td>1.62 ± 0.25b</td>
<td>1.58 ± 0.07d</td>
</tr>
</tbody>
</table>

For each specific variable (e.g. Start to 15 m) the same superscript letter indicates no significant difference (p < 0.05) within this specific variable; a different letter indicates a significant difference.


There are components of the swimming start, such as the underwater phase and break-out stroke, which are repeated with every turn the swimmer makes. Thus, any improvements made to the underwater components of the swimmer’s start can also apply throughout the race after every swimming turn. Technical modifications to the swim start have been found to reduce the swimming race time by 0.10 second, and when races have been won and lost by a tenth of this margin, an effective start is critical.

Turns

The swim turn is another important area when understanding the science of swimming faster. From research, underwater velocity has been commonly identified as the only variable that distinguishes elite swim turn performances. Athletes with an amputation are naturally asymmetrical and may find it more difficult to maintain balance, tending to oscillate more as they correct their balance, resulting in a less effective streamlined position. A similar scenario can apply to the swimmer with cerebral palsy. Applying the scientific principles of energy transfer through the kinetic chain suggests that loss of strength, coordination, or range of motion could result in inefficient force dissipation from the kinetic chain. The end result could be a less than efficient turn.

Analyses of the fundamental principles of a swim start and turn demonstrate that there are some
elementary differences for the swimmer with an impairment when compared to the able-bodied swimmer. However, the influence of a specific impairment on a swimmer’s ability to produce an effective start or turn has received comparatively little discussion within the research literature. This is considered a shortcoming of previous studies, as the Paralympic classes are a collection of different abilities, and the level of physical function within these classes naturally varies.

**Stroke rate, stroke length, and velocity**

The stroke rate in swimming is defined as the number of strokes per unit of time (stroke per minute), and is measured using a base three (or similar) stopwatch. The stroke length is the distance that the body travels during one arm stroke (from the entry in the water of the hand at the first cycle to the entry in the water of the same hand at the second cycle), and is measured in meters per stroke. The velocity, which is the product of stroke rate and stroke length, can also be measured as the distance traveled divided by the time. Elite swimmers and coaches are able to determine the best ratio between stroke rate and stroke length for the specific distance they are swimming. Furthermore, an elite swimmer can manipulate the stroke rate, and/or the stroke length, without causing detriment to the other variable.

The velocity profile within a 100-meter swimming race generally decreases by around 3.5% per 25-meter section of the race, with a slightly higher decrease of 5.9% following the turn (this will vary for each individual swimmer). To achieve a certain velocity, the swimmer adopts an individual ratio between stroke rate and stroke length. The stroke rate generally decreases by 6% at the beginning and then by 1.5% over the remaining sections of the race. The stroke length first increases by ~2%, followed by a ~3% decrease for the remaining 25 meters. This relationship between rate and length can be manipulated by the sport scientist and coach.

**Application for functional swimmers (S1–S10)**

From sport science analyses of the 100-meter freestyle finalists at the 2000 Sydney Paralympic Games, it was found that races were won or lost by better maintaining velocity in the second half of each 50-meter race lap, and that differences in velocity between swimmers were more related to stroke length than stroke rate (Daly et al., 2003). This knowledge is essential to guide training strategies for the Paralympic swimming coach; that is, to keep the stroke long, rather than increasing the stroke rate. Changes in swimming velocity within the race were more related to changes in stroke rate. Furthermore, changes in stroke rate were also responsible for velocity changes between qualifying heats and finals in the first part of races. Stroke length was responsible for better velocity maintenance at the end of races.

**Coach’s Corner**

Recognizing differences in strategies between classes is important and may be the key to optimizing performance for Paralympic swimming. The majority of results for stroke parameters between the classes suggest that, in accordance with research in able-bodied swimming, focusing on stroke length is important for achieving optimal race time. These results suggest that swimmers should concentrate on using a long stroke and taking fewer strokes per lap for 100-meter events to achieve the optimal race time.

In a more recent study, 724 official finals times were analyzed for 120 male and 122 female Paralympic swimmers in the 100-meter freestyle event at 15 national and international competitions between 2004 and 2006 (Fulton et al., 2009). Separate analyses were performed for males and females in each of four Paralympic subgroups: S2–S4, S5–S7, S8–S10, and S11–S13. Swimmer performance progressed by ~0.5% per year for males and females. Typical variation in mean performance time between competitions was ~1% after adjustment for the ability of the athletes in each competition, and the Paralympic Games was the fastest competition. Taking into account variability, progression, and level of competition, Paralympic swimmers who want a substantial increase in their medal prospects should aim for an annual improvement of at least 1–2%, which is higher than the current 1% for Olympic swimmers.
Impairment-specific swimming profile

As there are specific and unique biological requirements associated with particular physical impairments, an overview of the classification of the impact of impairment on performance in Paralympic competition will lend clarity to the subsequent discussion; the fundamentals of classification are treated much more comprehensively in Chapter 7. The original classification system was based on a medical model and athletes competed within five classes of disability: athletes with an amputation, defined as having at least one major joint in a limb missing (i.e., elbow, wrist, knee, ankle); athletes with cerebral palsy, defined as having the cerebellar area of the brain affected, which, through palsy, affects the control of movement; athletes with a spinal cord injury or other condition that causes at least a 10% loss of strength in the lower limbs (e.g., traumatic paraplegia or tetraplegia); athletes with a visual impairment (i.e., perception of light or hand movement to a visual acuity between 2/60 and 6/60 and/or a visual field of $>5^\circ$ and $<20^\circ$); and athletes categorized as “les autres,” a French phrase meaning “the others.” This group includes athletes who do not fit within one of the other impairment groups, but nevertheless have a permanent physical impairment (e.g., one femur shorter than the other, resulting in a significant difference in leg length). These athletes have a permanent physical impairment but they do not technically meet the criteria of amputation or spinal cord injury, so they are part of the les autres group.

Swimmers with an amputation

The swimmer with an upper-limb amputation tends to have an increased stroke rate and shorter stroke length, when compared to a swimmer with fully functional upper limbs. Naturally, swimmers with an upper-limb amputation rely more on their ability to kick, as this directly translates to their swimming performance. Despite the loss of the upper limb, maintaining musculoskeletal symmetry is paramount and swimmers should be encouraged to use an adapted hand paddle to provide necessary resistance to the amputated limb during training. This load will then facilitate hypertrophy around the remaining musculature and aim toward developing musculoskeletal symmetry for the athlete. Based on the biomechanics of body roll and developing swimming forces, swimmers should breathe on their amputated side, as this will enable the intact limb to remain longer underwater and therefore generate propulsive force. From sport science observations, the majority of swimmers follow this profile. However, if the swimmer feels more comfortable breathing to the other side, that should determine the side of breathing.

A UK-based study examined changes in the propulsive force and stroke parameters of arm-amputee and able-bodied swimmers during tethered swimming (Lecrivain et al., 2010). Eighteen well-trained female swimmers (nine unilateral arm amputees and nine able-bodied) were videotaped performing maximal-effort 30-second front-crawl swims, while attached to a load cell mounted on a pool wall. Tether force, stroke rate, stroke-phase durations, and inter-arm angle were quantified. The able-bodied group produced significantly higher mean and maximum tether forces than the amputee group. The average of the intra-cyclic force peaks was very similar for both groups. Average and maximum tether force had significant negative associations with 100-meter swim time for both groups.

Coach’s Corner

Swimmers with a lower-limb amputation should be able to maintain a similar stroke rate and stroke-length profile to able-bodied swimmers. The timing and type of kick, however, may vary. Swimmers with a lower-limb amputation tend to utilize a “cross-over” kick. There is also a higher than normal issue with shoulder injury for lower-limb amputees. This is attributed to the increased load on the shoulder on the opposite side to the leg amputation, as this shoulder needs to “skull the water” to maintain balance in the water as well as generating underwater force. As with swimmers with an upper-limb amputation, lower-limb amputees should also be encouraged to use a modified fin during training to provide the required overload for their residual stump and subsequently develop musculoskeletal symmetry. The use of the modified fin can improve the swimmer’s balance in the water and therefore reduce injury.
Both groups exhibited a similar fatigue index (relative decrease in tether force) during the test, but the amputees had a significantly greater stroke-rate decline. A significant positive association between stroke-rate decline and fatigue index was obtained for the able-bodied group only. Inter-arm angle and relative phase durations did not change significantly during the test for either group, except for the recovery phase duration of the arm amputees, which decreased significantly.

Consider some of the ways in which a physical impairment can have an impact on stroke technique. A swimmer with a lower-limb amputation, for example, will likely be able to maintain a similar body line, stroke rate, and stroke-length profile compared to an able-bodied swimmer. The timing and type of kick utilized, however, may vary depending on the extent of the impairment. Swimmers with a lower-limb amputation tend to utilize a “cross-over” kick; that is, to kick down on one side in time with the alternate arm stroke, and then to cross over and kick on the other side to counter that arm stroke. Some swimmers have utilized the typical one-side-only kicking, but this tends to inhibit their longitudinal body roll in the water.

Swimmers with cerebral palsy

Swimmers with cerebral palsy generally have two distinct profiles that relate directly to the level of severity of the impairment. For swimmers with mild cerebral palsy, their swimming stroke will initially be very similar to an able-bodied athlete. That is, the stroke rate, stroke length, and overall technique will be consistent, but over a short period of around 30 seconds, the technique will deteriorate because of the impairment. For swimmers with mild cerebral palsy, the level of fitness is not the critical factor in the change of technique; rather, it is the consequence of the impairment. This fatigue will then tend to exaggerate any asymmetry between stroke sides, which can lead to an increased risk of injury or require the swimmer to adopt novel strategies for generating propulsion. From a sport science analysis, the mechanism to address this issue is to establish a lower-intensity race strategy in the earlier stages of the race, as this will enable the athlete to counter the effects of fatigue in the later stages. That is, to control or “hold back” the swim in the first half of the race, swimming with good technique, as this will prepare the swimmer for the back half of the race.

For swimmers with a more severe level of cerebral palsy, the ability to control their technique can become a challenge, and therefore the focus on following a traditional swimming technique should be reduced. This may require adopting alternative skills such as swimmers lifting their head (more than the typical swimmer) so as to enable their mouth to clear the water for breathing, or incorporating a “scissor kick” to provide balance to their arm stroke and/or produce kick propulsion. The athlete and coach need to identify a stroke profile that the swimmer can maintain and explore the propulsion and resistance profile further. Temperature regulation is also a key issue for swimmers with cerebral palsy, in particular cold; that is, a water temperature of less than 26 °C.

Coach's Corner

Sport science analysis has found strategies such as increasing the use of dry-land warm-up so that the time spent in the water can be maximized for main-set swimming. A similar process for a greater dry-land warm-down in which swimmers may conduct their warm-down out of the water can also be adopted. Finally, some swimmers with cerebral palsy may be more emotional in a stressful situation, such as competing at the World Championships or Paralympic Games. This is a function of the athlete’s impairment, and knowledge of this can alert the coach and support staff prior to this possible issue becoming a problem.

Swimmers with a spinal cord injury

Swimmers with a spinal cord injury have two key factors to consider, the first of which is to avoid overloading the shoulder, as these athletes rely on the shoulder to propel their wheelchair (with a possible shoulder injury daily mobility will subsequently be impaired). This issue can be addressed by careful monitoring of the athlete’s range of movement internally and externally using a regular sport science screening measure, as discussed in Chapter 4. This will enable valuable feedback on the intensity levels of both the in-water and dry-land training regimes. Improving the musculoskeletal symmetry around the shoulder can
balance the shoulder and therefore better prepare the athlete for the rigors of sport.

Similarly, the loss of abdominal control and core stability associated with a spinal cord injury can affect the swimming technique (depending on the location of the spinal lesion). The potentially smaller propulsive surface associated with the physical disability, or an unbalanced capacity for propulsion, when compared to an able-bodied swimmer can also influence the swimmer's mechanics.

**Coach's Corner**

Sport science has assisted in this issue by having the swimmer utilize a “pull-buoy” when swimming in the prone position (see Figure 10.2). The flotation of the buoy in the water actively encourages extension of the hip joint. This alone will not resolve the situation and the athlete in a wheelchair, regardless of the sport in which they participate, should daily extend the hip joint to avoid a more permanent fixed contracture.

**Swimmers with a visual impairment**

Swimmers who have a visual impairment will generally follow the same swimming mechanics and technique as an able-bodied swimmer, as they have nearly the same physical abilities. There may be some minor variation in swimming technique in the early stages for these athletes, however, such as when they are approaching the end of the swimming pool. In some cases, this will diminish with experience; the swimmer may be cautious when approaching the end of the pool due to the difference in visual acuity (and they do not want to run into the end of the pool).

Broadly speaking, there are no physical differences between an Olympic swimmer and a swimmer with a visual impairment or blindness. Nevertheless, the lack of vision can affect the opportunities to take part in training and competition and the ability to learn proper swimming technique. This may require an alternative method of communicating between the coach and athlete when considering stroke correction. Finally, the potential to monitor one's race speed patterns through visual feedback on other swimmers was initially thought to be restricted. However, visual impairment or blindness has been found not to influence the race strategy in a 100-meter race.

![Figure 10.2  Swimmer with pull-buoy.](image-url)
when Paralympic swimmers are compared to Olympic swimmers (Burkett et al., 2010).

**Coach’s Corner**

When comparing Olympic swimmers and swimmers with a visual impairment at the 2000 Sydney Games, within the four clean swimming sections of the 100-meter event there were no significant differences in stroke rate. Despite the difference in average swimming velocity, as the stroke rate was not normalized for time, this suggests that a very similar race strategy is adopted by both the Olympic and Paralympic swimmers. “Seeing” the opposition may not be as important as initially thought.

**Swimmers with an intellectual impairment**

Swimmers who have an intellectual impairment will also follow the same swimming mechanics and technique as able-bodied swimmers, as they have nearly the same physical abilities. Studies have found that high-performance athletes with an intellectual impairment have fitness levels equal to or lower than able-bodied counterparts (Van de Vliet et al., 2006).

For swimmers with an intellectual impairment, any caution they experience toward the end of the pool will diminish as their confidence grows. From analyzing the swimming race strategy for swimmers with an intellectual impairment, the components of speed, stroke rate, and stroke-length patterns do not appear to be different to other competitive swimmers. Swimming speed decreases as the race progresses in a stable way (Daly et al., 2006; Einarsson et al., 2015). Most importantly, the swimmer with intellectual impairment should be aiming for a similar “able-bodied” model of swimming technique.

**Measurement tools**

There are a number of technical devices developed to measure swimming performance, and as Paralympic swimmers require a more sensitive analysis of the propulsion and drag relationship, this technology is important to understand the science of swimming. These measures can be done both in water and on land. An in-water measure will provide a snapshot of what is happening when swimming through the medium of water and will naturally include all of the propulsion and drag components of swimming. Sometimes a more specific measure of one component is required, such as just propulsion (without the influence of resistance) so as to allow a more detailed analysis and provide vital feedback to the athlete and coach on swimming performance. The use of technology will then allow informed decisions to be made on any technique modifications for the Paralympic swimmer.

**In-water measures, video, and inertial sensors**

A velocity meter is a device that can measure the instantaneous velocity of the swimmer, continuously and in real time. Other applications are to measure the ability to maintain a streamline as the swimmer pushes off from the wall or during the underwater phase of the swimming start. For example, traditionally a swimmer will maintain an underwater streamline phase for as long as possible before gradually rising to the surface of the water. The Paralympic swimmer may have an impaired ability to hold an effective streamline (arm amputee or athlete with cerebral palsy) or have an inefficient single-leg kick. The biomechanical measure of instantaneous velocity will enable the optimum underwater time to be determined for the
Paralympic athlete. Using these types of devices the passive drag of the swimmer can also be measured, information that can quantify how streamlined the swimmer is when moving through the water (see Figure 10.3). Other applications of this information can objectively evaluate the current swimming classification system (Oh et al., 2013).

There are several other applications of this measure, such as monitoring velocity fluctuations within the high-drag strokes such as breaststroke. By quantifying the athlete’s velocity, the correlation with other biomechanical measures of stroke rate can be investigated, enabling the optimum stroke rate to be determined. When used as a resistive device or tether, the velocity meter can provide an insight into the swimmer’s stroke-by-stroke force production and anaerobic power.

Video is another technology that is very useful to provide feedback on starting, turning, and freestyle technique. This technology can allow the relationship between arm-stroke timing within the complete swimming stroke, as well as the inter- and intra-swimmer variability, to be quantified. From this information the timing of the swimmer’s stroke can be modified, which is particularly important for Paralympic swimmers. For example, the swimmer’s stroke may be quantified as a catch-up stroke, in which the hand effectively “catches up” to the opposite hand at the front of the stroke.

The style of technique generally suits swimmers with a powerful leg kick and/or a powerful stroke. Paralympic swimmers may need to modify their index of coordination based on the measurement of instantaneous biomechanical swimming velocity.

**Coach’s Corner**

Optimal swim mechanics and subsequently swimming technique can be developed by the coach and sport scientist by first watching how the swimmer is moving though the water. An effective way to document this is to use a video camera, as this will provide a picture of the swimming, allow for features such as slow motion, and more importantly provide a time point for comparison. When making changes to the swimmer’s mechanics, coaches rely on their fundamental understanding of what is required when moving through the water, which is to increase propulsion and reduce resistance. For the swimmer with an impairment, there may be a range of different techniques for moving through the water. The key to success is just to apply the fundamentals of propulsion and resistance.

The recent developments in micro-technology have enabled previously unknown swimming measures to be conducted, such as determining the swimmer’s kick count and kick rate. The kick is typically hidden within the turbulent white water of the swimmer, and the kick rate is typically too fast to be measured by the human eye. Small inertial sensors, approximately 25 mm long and 8 mm...
thick, weighing less than 20 g, can be attached to the swimmer’s leg to measure this new sport science variable (see Figure 10.4). This knowledge can then be utilized by the swimming coach to design the training program effectively and develop the appropriate race strategy.

**On-land swim bench**

The coordination of the key body segments in swimming is of particular interest for the swimmer and the coach, as understanding these body-roll patterns can identify whether a swimmer is maximizing the musculoskeletal leverage within the body, or potentially moving in an anatomically unsound path that could cause injury. Studies of swimming have been investigated both in water and on dry land using equipment such as a swim bench to quantify the angle and timing of body roll (Lecrivain et al., 2010; Psycharakis and Sanders, 2010). Debate exists around the timing of the body roll – that is, the time point within the arm stroke when longitudinal rotation occurs – and the sequence in which the segments of head, chest/shoulders, and hips move.

Dry-land sport science research on the timing and sequence of the body roll has found that for the breathing stroke, the head roll occurred at ~30% of the underwater propulsive phase, the chest at ~42%, and the hips at 47% (Lee et al., 2007). However, during the non-breathing stroke the timing and sequence changed, with maximum hip roll occurring early, at 20% of the propulsive phase, followed by the chest and hips at 34% of the propulsive phase. A reason for early hip roll may be to facilitate greater recruitment of the large torso muscles within the stroke or due to leg kick. The knowledge of timing and sequence has guided the coaching of swimmers and provided the coach with a greater understanding of swimming mechanics.

**Swim-start technology**

Sport science technology has been specifically developed to measure the swimmer’s start objectively, which includes leaving the block and entering the water. To understand the relationships requires specific understanding of the forces generated on the starting block and the position, velocity, and acceleration of the human segments as they leave the block and enter the water. The development of synchronized above-water and underwater cameras, the mounting of force plates onto starting blocks, or the finishing pad on the wall have all enabled objective measures to be made in the swimming pool.

The influence of fine adjustments to the starting position has been quantified with swimming technology. For example, to determine the influence of the swimmer’s upper-limb position on their center of gravity as they are poised on the starting block can be determined and used to guide the
starting position. Stability on the block is critical, as any movement prior to the starter’s gun will result in disqualification under the one-start rule. Paralympic swimmers who have reduced balance control, such as lower-limb amputees or those with cerebral palsy, can find balancing on the starting block difficult.

**Swimming training and coaching practice**

As with any sport science measure, the most effective test protocols are implemented on a regular basis, allowing for feedback and the current status of performance to be evaluated. The step test was developed to assist in understanding the current fitness status of the swimmer, and to enable the effectiveness of a progressive training program to be assessed. The test set is best conducted in a pool of the same length, and to prepare for a typical long-course competition this is a 50-meter pool. For Paralympic swimmers, the step tests contain six or seven 100-meter repeat swims; Olympic swimmers tend to use seven 200-meter swims (higher-level Paralympic swimmers could adopt this model if the coach desired). The step test is designed to train swimmers to pace their main event as efficiently as possible and to determine the lactate threshold. Using the swimmer’s personal best 100-meter time plus 2 seconds as the target for their final swim, the six 100s (or 200s) are swum at a descending pace. The swimming variables of stroke rate, distance per stroke, free-swimming velocity, stroke count, turn time, lap time, total time, and lactates are recorded for each swim. All swims are conducted at the same time interval, so the intensity will progressively increase, as with any test set. Starting at the personal best time plus 25 seconds, the swimmers are encouraged to pace the 100-meter or 200-meter swim evenly. These measures enable the swimmer’s ability to be quantified, and based on this knowledge the training program can, if required, be modified. Like any step test, these protocols were first established for Olympic swimmers and will vary around the world, but in essence contain a step test and efficiency measures.

A second measure is the stroke-efficiency test protocol, which is designed to develop the swimmer’s efficiency. The test involves swimming six 50-meter swims at the pace of the swimmer’s second 50-meter of 100 meters. The swimmer counts the number of strokes they take to swim the 50-meter interval and the time for the swim is also recorded. These two values are added together (the stroke count and time) to produce a golf-type handicap score. The aim of the test is to reduce the swimmer’s handicap by either using fewer strokes for the same time, or recording a quicker time for the same number of strokes.

Finally, variables such as the start and turn that are measured in the race analysis can also be tested on a regular basis within training. For example, to measure the turn, the swimmer can be positioned at around 20 meters out from the wall. This will enable sufficient time to reach race velocity into the wall. To measure the “turn-in” part of the turn, the coach can measure the time from when the swimmer’s head crosses the 5-meter backstroke flag mark until the feet touch the wall. The time from “feet on the wall” until the swimmer’s head passes the 5-meter window will determine the turn-out time. This simple sport science measure will enable the effectiveness of the turn to be quantified within the training session. A similar process can be applied for the start, with timing measures made at the 5-, 10-, and 15-meter intervals (or as required by the coach).

**Coach’s Corner**

To recover between a same-day heat and final, or to ensure that a swimmer with many events at a competition is not overloaded with additional warm-downs, alternative recovery strategies have been used by several leading swimming nations (USA, UK, Canada, Germany, Australia, and Ukraine). For swimmers who utilize a wheelchair (who are naturally dependent on their shoulders for both swimming and daily mobility), using only swimming as the form of recovery has resulted in elevated lactate levels. The alternative is a combination of swimming (~300 meters) and pushing the wheelchair for an effective recovery. From this new sport science knowledge, a better understanding of the appropriate recovery strategies has been established, and more importantly a specific schedule can be developed for each individual swimmer.
**Individual recovery strategy**

Appropriate recovery is critical to swimmers’ performance, particularly when they must recover from a morning heat session before the final that night. Furthermore, the 7–9-day demands of a World Championship or Paralympic Games will require that the athlete can suitably recover from an event early in the program and avoid any deterioration in performance as the competition goes on. Sport science has effectively guided the recovery strategies for Paralympic athletes, in particular, to address the unique physiological features that each disability may possess.

Using the commonly accepted sport science measures of lactate production and rating of perceived exertion (RPE), an appropriate recovery strategy can be developed for each individual swimmer. Sport scientists have found that rather than employing the standard ∼1,000-meter swimming warm-down for each swimmer, alternative modes of recovery are more effective. For example, a swimmer who has an arm impairment (arm amputation or loss of function) relies predominantly on the leg kick for swimming performance. Making this swimmer swim after a race can increase blood lactate levels, rather than reducing them. A more effective form of recovery includes a combination of swimming (∼300 meters) and walking.

**Future directions**

The physical impairment of the Paralympic swimmer naturally challenges the traditional understanding of how a human moves through the water. Sport science can help to quantify objectively what is happening as the Paralympic athlete swims, and this new knowledge places far greater demands on the current established guidelines for swim coaching. The priority areas for future swimming knowledge are to better understand the adaptation process for people with an impairment when in the aquatic environment, and to utilize this new knowledge to enhance sport performance and provide safety measures for the athlete.

While Paralympic swimmers are taking advantage of many of the sport science methods that able-bodied swimmers are using to improve performance, there are still a number of opportunities where advances in Paralympic swimming could be made:

- Appropriate and regular feedback is required from the coach to the athlete to help everyone better understand the factors contributing to performance and identify areas where athlete-specific improvements can be made. This can include obtaining race analysis data from competitions and/or recording basic performance data during training.
- There are opportunities to develop impairment-specific equipment, particularly for spinal cord-injured athletes and swimmers with a more severe impairment, which can help enhance performance within the rules of the sport. For example, this could include utilization of flotation devices (pull-buoys) in strategic positions (ankle or knee or hip).
- Gaining a more thorough understanding of how and why the human body moves and, as importantly, the factors that limit or enhance the capacity to move is critical to any sporting performance, but especially so for athletes with impairment. What is needed is the application of the tremendous technological developments in various spheres of human endeavor to the challenges faced by Paralympic athletes.

**References**


Contribution of sports science to performance: Swimming

Contribution of sport science to performance: Nordic skiing

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Introduction

Scientific literature related to Nordic skiing began appearing at the beginning of the 1980s related to both biomechanics (Ekström, 1981; Komi et al., 1982; Viitasalo et al., 1982) and physiology (Rusko et al., 1980). During those years, only classical skiing (known as diagonal skiing) was used in competitions. The research work of the time concentrated on the biomechanical and physiological aspects of that particular technique. Classical techniques can be divided into double poling (DP), kick double poling, diagonal stride (DIA), and the herringbone technique, commonly used on steeper uphill parts of the track in which the grip is not sufficient for the diagonal stride. In the mid-1980s different skating techniques, later named in the scientific literature Gears 1–5 (G1–G5; Nilsson et al., 2004) or V1, V2, and V2 alternative (Smith, 2003), were introduced and started receiving attention in the scientific world. However, only a few studies related to skating techniques were published before the year 2000. Since then, scientific research on skating techniques has become much more prominent.

Biomechanical analyses have most commonly been conducted by combining two-dimensional (2D) or three-dimensional (3D) motion analysis with different types of force measurements. Pole forces have typically been measured with sensors implanted in poles measuring the resultant force, or with force plates allowing differentiation between vertical and horizontal forces (see Figure 11.1). Force plates have also been used to measure leg forces, but mostly with the classical techniques. More often, however, leg forces have been measured either with pressure insoles to obtain the resultant force, or with sensors that have been attached to the ski bindings, allowing for measurements in three directions. Recently, treadmills equipped with force sensors have been used (Kehler et al., 2014). Measurements of muscle activation using electromyography (EMG) have often been synchronized to kinematic and kinetic measurements. More recently, the use of accelerometers and inertial measurement units (IMU) has increased significantly in many aspects of sport science research. In this regard, Nordic skiing is not an exception. Accelerometers have been used, for example, to differentiate between varying skiing techniques and to calculate skiing cycle characteristics.

For physiological measurements it has been common to measure heart-rate variables, blood lactate, oxygen uptake, and other respiratory parameters such as ventilation. In relation to poling, breathing patterns have also been studied. Some studies have been published with oxygen (O₂) extraction, positron emission tomography (PET), and
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Near infrared spectroscopy (NIRS). Surprisingly, little research has examined fatigue and strength training. Both females and males have been used as participants, but only a few papers have examined gender issues (Sandbakk et al., 2012, 2014). When gender differences in skating technique were studied, it was found that men had a 17% higher maximal speed during which their cycle lengths were 21% longer than women, while no differences were observed in cycle rate. During the submaximal speed of 3.9 m/s, both cycle lengths and cycle rates were 11% higher than in women. VO_{2\text{max}} was 14% higher in men relative to total body mass and 7% relative to fat-free body mass. No major differences were observed in work economy. The most substantial gender differences have been shown in DP when compared to skating skiing, DIA, or running. It was concluded that gender difference in performance is enhanced when the contribution from poling increases, thus highlighting the role of upper-body strength.

![Diagram of individual pole force-time curves during DP in both vertical (Fz) and horizontal (Fy) directions.](image)

**Figure 11.1** Examples of individual pole force–time curves during DP in both vertical (Fz) and horizontal (Fy) directions. *Source:* Mikkola 2013. Reproduced with permission of Taylor & Francis.

### Coach’s Corner

When gender differences in skating technique were studied, it was found that men had a 17% higher maximal speed during which their cycle lengths were 21% longer than women, while no differences were observed in cycle rate.

The importance of the contribution of the arms has been shown in several studies with able-bodied athletes. In skating technique with and without poles, 15% higher peak velocity and 10% higher peak VO_{2} were observed with poles (Sandbakk et al., 2013). This was accompanied by a 30% longer cycle length, smaller angles between skis, and a higher gross efficiency. Oxygen extraction during diagonal skiing was higher in legs than in arms, but EMG was higher in arms, both at 90% and 70% of VO_{2\text{max}}, and the reduction with decreased workload was more pronounced in the arms (Björklund et al., 2010). It is also important how the arms are used,
since an effective arm swing increases the force production of the legs and thus performance.

Most of the published scientific work has been conducted using roller skis on a treadmill or ski ergometer in standard laboratory conditions (Lindinger et al., 2009a,b; Pellegrini et al., 2013; Stögl and Holmberg, 2011; Sandbakk et al., 2013). However, some studies have been conducted also on natural snow conditions (Andersson et al., 2014; Leppävuori et al., 1993; Ohtonen et al., 2013; Vähäsöyrinki et al., 2008). In general it seems that for able-bodied athletes the kinematic, kinetic, and physiological behaviors are quite similar regardless of whether the test has been performed on a treadmill, ergometer, or on snow. It has been shown that the power output generated on an ergometer modified for DP has a high correlation with DP performances on snow (Forbes et al., 2010). In addition, there was a significant correlation between the power on the ergometer and the power applied to the poles on snow. The ergometer was also shown to be reliable, as there was no statistical difference in test–retest of 60 s power output or VO$_{2}$peak measurements. It was demonstrated that 10 km classical skiing race speed correlated significantly with power and VO$_{2}$peak, but the correlation was stronger with power than with oxygen uptake. We found in our own experiments that the ergometer was fairly well aligned with skiing on snow in terms of cycle characteristics, force production (see Figure 11.2), and muscle activation (Halonen et al., 2014).

On the treadmill, however, during classical skiing the roller ski’s grip (static friction coefficient) may influence the outcome. Both gliding properties and capability to produce horizontal forces can be different than on snow. It has been reported that oxygen consumption in DIA and DP with kick was 14% and heart rate 7% higher, while the

![Figure 11.2](image-url)

Figure 11.2  Cycle time (A), cycle length (B), poling time (C), and peak pole force (D) with three submaximal speeds and maximum speed when skiing on snow and using an ergometer. Source: Halonen 2014. Reproduced with permission of Meyer & Meyer Sport.
propulsive forces from the legs were lower with roller skis, with a similar coefficient of friction to on-snow skiing (Ainegren et al., 2014). In addition, except for the absence of negative braking forces in roller skis, a treadmill equipped with force sensors gave similar force profiles as were earlier reported for force plates covered with snow by Vähäsöyrinki et al. (2008).

All the countries that compete in Nordic skiing spend considerable time and effort on equipment testing. Field tests are used by everyone, but also scientific research methods using IMUs (Breitschdel et al., 2012) and a special ski tester (Linnamo et al., 2008) have been developed and published, in particular to study the gliding properties of the skis. Some research has also been published focusing on pole properties (Swarén et al., 2013). The equipment plays an important role and the research methodologies described earlier would be available both for able-bodied athletes and for athletes with an impairment. Although there are some differences in DP between standing and sitting athletes, the following will mainly deal with the aspects related to DP, which has been studied quite extensively during the past decade in able-bodied skiers.

**Coach’s Corner**

Skiing on snow throughout the year is not possible in most countries. Therefore the use of roller skis both outside and on a treadmill has helped to maintain technique-specific training outside the winter period. Even though some differences, mostly related to gliding friction as well as to static friction during diagonal skiing push-offs, exist between skiing on snow and roller skiing, it seems that they resemble each other quite well and can therefore be used for testing and training. Specific track profiles can even be simulated on a treadmill, which can help to prepare for upcoming races. As in many other sports, ergometers have been developed also for cross-country skiing and in particular for the upper body. Based on scientific research, these ergometers can also be recommended as testing and training tools for both able-bodied athletes and athletes with an impairment.

**Double poling**

In classical skiing the use of DP has increased during the past years, in particular after sprint skiing competitions started in the 1990s. In DP the force is transmitted to the track by the poles and no grip wax is needed. It seems that in the future the relative use of DP may increase, even in long-distance races. In the World Cup 15 km classical race in December 2014 in Davos (Switzerland), for the first time three skiers in the top ten skied the whole race using DP, and the race was won with this technique for the first time in Toblach (Italy) in January 2015. As with other techniques, the velocity of the skier is determined by the length of the distance the skier travels with one push (cycle length) and how often the push is repeated per time unit (cycle rate). Normally, to increase the skiing velocity both cycle length and cycle rate are increased. It has been shown, however, that the better skiers can rely more on cycle length at the same absolute speed. Better skiers have also been shown to have shorter ground contacts, higher pole forces, higher elbow and hip flexion velocities, and smaller minimum elbow, hip, and knee angles. As well as how elite skiers control their DP speed, how skiers coordinate their body movements to change the poling speed has also been measured (Lamb et al., 2014). It has been shown that coordination can be highly individual and much more variable in response to changing speeds than can poling frequency or cycle length (Lamb et al., 2014). Thus, there are several ways to produce the movement to achieve a certain outcome, which presents additional challenges to technique training.

As had earlier been reported in DIA (Norman et al., 2013), in DP as well with higher velocities and proper technique the utilization of elastic energy through a stretch-shortening cycle type of movement can be possible. Figure 11.3 shows the effect of DP skiing velocity on the elbow joint angle and pole force in one elite skier, and Figure 11.4 the difference in force curves using two different strategies. It is clear from the figure that power production is higher with the skier utilizing strategy A. This strategy is therefore more optimal, at least for the sprint performance. It could, however, be more fatiguing and it remains to be studied how the race distance would affect it.

There is evidence that the DP technique may be most economical when skiing on the flat or slightly uphill, while in a steeper uphill climb this advantage is lost (Pellegrini et al., 2013). When the skiers
were allowed to choose their technique, they preferred DP on flat terrain and changed the technique with increasing slope to DP with kick or DIA. In DP with the skiing velocity of 15 km/h, the maximal oxygen uptake was shown to be 13.9% lower as compared with DIA at 11.5 km/h in which both legs and arms are utilized fully (Holmberg et al., 2006). Similar observations regarding VO$_{2\text{max}}$ have been reported also when comparing DP to DIA with the same absolute skiing velocities (Doyon et al., 2001;  

**Figure 11.3**  Elbow angle (A) and resultant pole force (B) curves of one elite cross-country skier with different DP velocities from very slow (9 km/h) to maximum velocity ($V_{\text{max}}$). Source: Lindinger 2009a. Reproduced with permission of Springer.

**Figure 11.4**  Comparison of the resultant pole force curve between two athletes (A + B) representing two different DP strategies (A and B). Time courses are mean ±SD. Strategy A = high impact pole force (PFI), shorter time to peak pole force (TPPF), higher peak pole force (PPF), shorter poling time (PT), and higher poling frequency (Pf); Strategy B = high impact pole force, longer TPPF, lower PPF, longer PT, and lower Pf. PFI, impact pole force; TPPF, time to peak force; PPF, peak pole force. Source: Lindinger 2009b. Reproduced with permission of Wolters Kluwer Health, Inc.
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Figure 11.5 Representative DP coordination pattern, including EMG rms of upper-body muscles at 85% of Vmax for one subject (the best skier in the group). The data are mean values. Rectus abdominis (RA), obliquus externus abdominis (OBLe), latissimus dorsi (LD), pectoralis major (PMa), triceps brachii (caput longum) (TRI), flexor carpi ulnaris (FCU), erector spinae (lumbar) (ES), and biceps brachii (BIC). The figure starts (from the left) at about half time of the recovery phase, followed by the poling phase (start at t = 0), and finishing with the end of the recovery phase. EMG rms levels are categorized into high, medium, and low. Source: Holmberg 2005. Reproduced with permission of Wolters Kluwer Health, Inc.

Coach’s Corner

Based on research findings, Swedish sprint skiers especially started developing and training a new modern DP technique in the early 2000s and successfully applied it at the Winter Olympics 2006 in Torino (Italy). The center of mass was lifted up higher during the recovery phase by lifting the heels and fully extending the hips, combined with a distinct lean forward of the body. This preparation phase to more properly position the body for pole plant was followed by a rapid “fall” into the poles, with a pronounced, fast flexion of all leg joints down to a deeper position during poling. Consequently, this allowed a clearly increased pole force production and a better use of the stretch-shortening cycle (SSC) type of behavior, in which the elastic properties of the muscle-tendon units in the arm and shoulder extensors are utilized. Additionally, stretch reflex components may play a role if the stretch is rapid enough. Several studies showed the importance and benefit of a more pronounced lower-body use in DP, which has also influenced how the technique has developed and how it should be taught and trained. In sit-skiers the use of the legs is restricted, but the utilization of the SSC may be possible also with the proper use of the upper body and marked flexion-extension patterns in elbow and shoulder joints. Whether this is really the case should, however, be scientifically verified.

Watts et al., 1993) as well as comparing DP with G3 skating (Sandbakk et al., 2015). These differences can be explained by the smaller muscle mass used in DP. EMG studies have shown that muscle activation during DP starts from trunk flexors and hip flexors, followed by the shoulder and elbow extensors (Holmberg et al., 2005; see Figure 11.5). When the velocity is increased, a clear pre-activation in upper-body muscles prior to the pole plant has been reported (Lindinger et al., 2009a).

When the effectiveness of the stretch-shortening cycle (SSC: calculated as an EMG relation between flexion and extension phases) in DP was studied, it was shown that it increased with increasing velocity in the triceps brachii and latissimus dorsi muscles accompanied by an increased pole force (Zoppirolli et al., 2013). The effectiveness of the SSC correlated positively with maximal speed. In that regard, modern DP technique is not exactly similar between able-bodied and sit-ski athletes; the latter are not allowed to use the lower-body muscles...
even if they would be capable of doing so. Indeed, it has been shown in able-bodied skiers that leg muscles are also activated during DP and that restrictions of knee and ankle-joint motions impair DP performance (Holmberg et al., 2006). Thus, modern DP is not only upper-body work and the usage of legs can increase DP speed by 9% and decrease endurance test time by 12%. Utilization of legs also affects skiing efficiency in DP. In a study where techniques were divided into a small and large knee range of motion with fixed heels and a large knee range of motion with free heels, it was found that higher lower-body utilization increased the performance measured as forward impulse during three 30-second experiments on a double-poling ergometer, but decreased the skiing efficiency (Holmberg et al., 2012). The importance of the lower body in DP was supported by experiments with glucose uptake and \( \text{O}_2 \) extraction in different muscle groups (Bojsen-Møller et al., 2010; Stöggl et al., 2013). During DP with 53% and 74% of peak \( \text{VO}_2 \), the most changes in glucose uptake from low to high intensity measured by PET were seen in the knee extensor and flexor muscles and abdominal muscles, while no major changes were seen in most of the upper-body muscles. \( \text{O}_2 \) extraction during 90% and 70% \( \text{VO}_{2\text{max}} \) in DP was associated with the time point of peak pole force, duration of recovery, EMG, and lower-body use. \( \text{O}_2 \) extraction was lower in arms than in legs at both intensities and decreased more in legs when the intensity was decreased. Oxygen saturation measured by means of NIRS differs between arms and legs and may be influenced by upper- and lower-body compressive garments (Cornachione et al., 2014). Compressions has also been shown to have some positive influences on skiing performance during a 5-minute treadmill test, with lower blood lactate values during the exercise (Heil and McLaren, 2014). On the other hand, Sperlich et al. (2014) concluded that the performance of well-trained skiers during 3 \( \times \) 3-minute DP sprints was not enhanced by upper-body compression.

**Fatigue**

Different fatigue protocols are often used in neuromuscular studies in an attempt to gain a deeper understanding of the mechanisms affecting performance. Inducing fatigue in athletes may provide additional information about why some of them are better than others. Depending on the length of the race and skiing velocity, different mechanisms are related to accumulated fatigue. Good aerobic condition is essential in cross-country skiing, but in DP, and especially in sprint skiing, anaerobic condition and neuromuscular properties may be the decisive factors between poor and top performances. Simulated cross-country sprint skiing may lead to a reduction in neural muscle activation along with decreased leg and arm forces, leading to a decreased maximal skiing velocity. Fatigue studies have shown that better skiers are better able to maintain pole forces and then have longer cycle length and speed toward the end of the exercise. We have seen this in our own experiments in short-distance simulated sprint skiing (see Figure 11.6) as well as with longer distances (Ohtonen et al., 2012).

It has been suggested that decreased hip and trunk flexion and the lower inclination of the pole due to fatigue reduce the effectiveness of force application, leading to decreased velocity. At the single muscle fiber level, it has been shown with repeated sprint skiing of 4 \( \times \) 1300 m that exercise increased \( \text{Ca}^{2+} \) sensitivity only in myosin heavy-chain (MHC) type II fibers taken from the triceps brachii muscle (Ørtenblad et al., 2014). Grasaas et al. (2014) examined how an incremental test to exhaustion affects submaximal skiing in elite skiers. It was found that oxygen uptake and blood lactate concentration were increased while gross efficiency and cycle lengths were reduced during submaximal roller-ski skating after the exhaustive exercise. Since no changes were observed in ski forces and peak power, it was concluded that the skiing technique had changed to be less efficient.

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**Coach's Corner**

Good aerobic condition is essential in cross-country skiing, but in double poling, and especially in sprint skiing, anaerobic conditioning and neuromuscular properties may be the decisive factors between poor and top performances, between winning a gold medal and coming in second place.
Performance and capability to resist fatigue can also be affected by cold temperature (Wiggen et al., 2013). Both DP sprint performance (30 s and 2 min) and DP test to exhaustion were examined in −14 °C and 6 °C. The decrease in power output during 30 s and 2 min DP sprint tests was about 5% greater after an 8-minute exposure in a cold (−14 °C) environment compared to a warmer (6 °C) temperature. In the exhaustion test, peak power output was about 7% and peak VO\(_2\) almost 8% lower in the cold temperature. It has been suggested that in sit-ski athletes exposure to cold weather could lead to the potential danger of hypothermia (Bernardi and Schena 2011). In the biathlon, fatigue may have an even bigger impact on the final performance, because in addition to impairing skiing fatigue can also affect shooting performance. This was shown in a study where 40 minutes by bike at 90% of max workload decreased shooting performance significantly (Sattlecker et al., 2014). In the prone position, the biggest differences in the measured shooting parameters after the fatiguing bike trial were observed in trigger force and shoulder pressure. This indicates that fatigue affects how hard the athlete squeezes the trigger and presses the rifle against the shoulder. Furthermore, the effects of fatigue were more substantial in low performers than in high performers.

**Training**

Some athletes have specialized in sprint events, in which strength and power can be even more important than in longer distances, where endurance capacities may play a bigger role. Even though this specialization has taken place, some athletes have been capable of winning both sprint and 30 km or 50 km races during the same championships. Although there is a vast amount of literature related to endurance training and strength training, not so many studies have been published related to Nordic skiing. The main reason for the lack of research in this area is probably related to the fact that it may be difficult to persuade elite athletes to make big changes to their normal training program. Additional issues may be that in an endurance sport especially, heavy strength training that could lead to muscle hypertrophy has been commonly avoided. To move a heavy muscle mass in an endurance sport such as Nordic skiing would require more work. Nevertheless, some studies have shown that strength training can have a positive effect on oxygen-uptake capacity (Losnegard et al., 2011). After three months of additional heavy strength training twice a week, it was found that VO\(_{2_{\text{max}}}\) measured during skiing increased after strength training by 7%, while no changes were observed in a running test.
(Losnegard et al., 2011). In the same experiment, the DP performance measured by a 5-minute treadmill test increased more in the training group than in the control group, while no clear differences were observed in a 100-meter sprint test.

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Heavy strength training that could lead to muscle hypertrophy has been commonly avoided. Nevertheless, some studies have shown that strength training can have a positive effect on oxygen-uptake capacity and improve performance.

In another study, it was reported that an 8-week strength-training program using a cable pulley, DP ergometer resulted in almost a 4-minute increase in time to exhaustion test and there was a significant improvement in work economy (Hoff et al., 2002). High-resistance training simulating DP for 9 weeks with 85% 1-repetition maximum (RM) load performed explosively led to an increase in 1-RM and a change in the force–velocity relationship. In this case, no changes were observed in VO$_{2\text{max}}$ but the exercise economy improved (Hoff et al., 1999). It seems that the training effects are muscle fiber type specific. Cross-sectional area of type I and type IIA fibers increased by approximately 11% and 24%, respectively, along with the number of capillaries per fiber after 20 weeks of increased DP upper-body training (Terzis et al., 2006). The greatest increases were observed in the MHC IIA fibers, while no changes were observed in I or IIA isoforms. The largest muscle adaptations were observed in the participants with the initially highest oxygen uptake, and for those individuals the performance also increased the most.

Training in hypoxic conditions has been shown to have positive effects on DP sprint performance. Faiss et al. (2015) conducted a study in which elite cross-country skiers performed in 2 weeks six sessions of 4×10-second sprints with 20-second recovery between the sprints in hypoxic (3000 m) and normoxic (300 m) condition. It was found that the number of sprints enhanced more (from 10.9 to 17.1) in the hypoxic group, while no change occurred in the normoxic group (from 11.6 to 11.7). In junior skiers, a 10-week upper-body training program with roller board increased their upper-body strength, power, and endurance significantly more than for the control group (Nesser et al., 2004). Mikkola et al. (2007) showed that although endurance training was reduced by 20% during an 8-week training period at the expense of explosive training, no decreases were observed in maximal aerobic capacity. The training did lead, however, to increases in explosive strength and more economical sport-specific performance.

**Coach’s Corner**

Fatigue studies have shown that performance does not depend only on the endurance capacity, but also on the capability to produce high power with a proper technique. Due to the special role of the upper body and the requirement of high power, especially in DP, the training protocols have changed in the past few years, or at least perhaps should change in the future. In order to activate fast-twitch muscle fibers, it is known from strength training studies that the training load needs to be near maximum or the movements need to be performed explosively. These fast-twitch fibers produce the highest forces and power and could be the decisive factor during the final sprint of the race. Since at the same time they cannot resist fatigue, the training must also include activation of the slow-twitch fibers. The few studies that have been published on strength training and cross-country skiing have shown that strength training does not impair endurance capacity. Despite this, heavy strength training among skiers is still mostly avoided. Increased muscle mass would increase the workload, but if mechanical efficiency also increased through increased power, the effect on overall performance for different race distances is not really known and should be studied.

**Paralympic Nordic skiing**

Although research in sit-skiing has been published, currently there is a lack of scientific research performed on standing skiing for athletes with visual impairment, amputee skiers, and athletes with cerebral palsy. Standing Paralympic skiers with visual impairment have been reported to have higher maximal VO$_{2\text{max}}$, heart rate (HR), and volume of expired air (VE) values than sit-ski athletes (Bhambhani et al., 2012). Additional scientific information regarding standing Paralympic Nordic skiers is difficult to find. Therefore, the rest of this chapter
will concentrate on scientific information addressing sit-skiing.

**Classification**

Before discussing the research literature dealing with sit-skiing, it is important to understand how the classification process is conducted in this sport. As in other Paralympic sports, the purpose of classification is to ensure the fulfillment of minimum disability criteria and to minimize the impact of impairment on sport outcome (Tweedy and Vanlandewijck, 2011). As some impairment may change over time, the impact on performance may also change. Therefore, athletes may undergo the classification process several times throughout their career. Recently, a new strength test battery consisting of seven isometric tests has been introduced to facilitate the development of evidence-based methods of classification (Beckman et al., 2014). This includes tests for both upper- and lower-body strength. Therefore, these tests could be applicable also to Nordic skiing. Sit-skiers are assigned to five different classes: LW10, LW10.5, LW11, LW11.5, and LW12 (LW = Locomotor Winter). Medical testing is based on the American Spinal Injury Association (ASIA) impairment classification. Neurological responses like touching or pinching selected parts of the skin are included in the test, as well as evaluation of the strength of the muscles controlling key motions of the body (Vanlandewijck and Thompson, 2011; Tweedy and Vanlandewijck, 2011).

In addition to the medical testing and observation of the athlete in competition, athletes’ capacity for stabilizing the trunk is tested using a specifically developed test-table-test (TTT). In this test athletes are asked to bend the trunk into all movement planes in a sitting position. Athletes are strapped to the table to ensure safety. The test is performed in a sitting position with flexed knee, while the buttocks and heels are on the same level (see Figure 11.7). The TTT includes the following four different tests: 45-degree hip flexion (forward leaning), 45-degree backward inclination, lifting a ball above the head, and a maximum trunk-rotation range. In each of these tests, the athlete is assigned a certain number of points based on test performance. Table 11.1

![Figure 11.7](image) Table test. Source: Pernot 2011. Reproduced with permission from Nature Publishing Group.

<table>
<thead>
<tr>
<th>Class</th>
<th>Impairment</th>
<th>Muscle activity (ASIA classification)</th>
<th>TTT score</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW 10</td>
<td>Lower limb and trunk</td>
<td>Unable to sit without strapping (muscle activity score 2)</td>
<td>0–2</td>
</tr>
<tr>
<td>LW 10.5</td>
<td>Lower limb and trunk</td>
<td>Sit statically without arm support (muscle activity score 2–3)</td>
<td>3–6</td>
</tr>
<tr>
<td>LW 11</td>
<td>Lower limb and trunk</td>
<td>Retained abdominal muscles and trunk extensor</td>
<td>7–10</td>
</tr>
<tr>
<td>LW 11.5</td>
<td>Lower limb(s) and trunk</td>
<td>Near to normal trunk muscles activation</td>
<td>11</td>
</tr>
<tr>
<td>LW 12</td>
<td>Lower limb(s)</td>
<td>Normal trunk function</td>
<td>12</td>
</tr>
</tbody>
</table>

summarizes the sport classes in Nordic skiing based on the impairment, muscle activity, and TTT score. All the classes compete in the same category. In competition, the final time is multiplied by a percentage based on the estimated impact of the impairment on the result. Each class has its own percentage, currently ranging from 86% (LW10) to 100% (LW12). These percentages have been calculated based on World Cup competition results from previous years. Whether these percentages and differences between classes are fair and justified has been a common topic of conversation among athletes, coaches, and Paralympic Games officials. To address this challenge, the International Paralympic Committee (IPC) recently initiated a project together with scientists who have experience in Nordic skiing. This is an ongoing project, with the latest measurements conducted during the 2014 World Cup race in Vuokatti, Finland. Some parts of this project will be described later in this chapter.

### Laboratory studies

For research purposes, it is common to use ergometers and to conduct the measurements indoors under highly controlled settings. This is done in order to standardize the research environment so that the data could be both repeatable and validated. In Nordic skiing, the environmental conditions and equipment have an enormous impact on performance and play a key role in determining athlete success. Therefore, it is important to compare how closely the laboratory conditions correspond to field conditions. To date, only a few studies with this focus and with sit-skiers have been published.

Spinal cord–injured persons have been reported to have lower power outputs and pole forces along with greater trunk extension at the beginning of the thrust phase and smaller trunk flexion at the end of the thrust phase in DP ergometer when compared to able-bodied skiers (Bjerkefors et al., 2013). In shoulder and elbow movement, no significant differences were observed between able-bodied and sit-skiers. When Nordic sit-skiers were compared with athletes from wheelchair sports in laboratory and field tests, it was found that skiers and distance-racing wheelchair users had higher \( VO_2_{\text{max}} \) values than wheelchair basketball players, fencers, and tennis players (Bernardi et al., 2010). When comparing Nordic sit-skiers to other winter sport athletes, the skiers had higher \( VO_2_{\text{max}} \) and upper-body strength than curlers, sitting alpine skiers, and ice sledge hockey players (Bernardi et al., 2012). Upper-body strength was similar between Nordic sit-skiers and sitting alpine skiers, but Nordic sit-skiers were stronger than curlers and hockey players. In Nordic sit-skiers, peak \( VO_2 \) values and blood lactate were similar in laboratory (incremental arm-cranking test) and 5 km field tests (Bernardi et al., 2010). A slightly different result was found when comparing the DP ergometer with a field test of \( 3 \times 3 \) minutes (Forbes et al., 2010). No differences were observed in peak \( VO_2 \), but HR and the respiratory exchange ratio were higher for the ergometer. In this case, the field test included turns and was therefore more intermittent and probably not directly comparable. In the study by Bernardi and Schena (2011), a positive correlation was reported in terms of cardiorespiratory response, and it was concluded that DP results on the ski ergometer were aligned with field conditions in elite Nordic sit-skiers. Whether this is also true with biomechanical variables and whether the impairment level is related to possible differences between natural skiing and ski ergometer remain to be studied.

### Coach’s Corner

The shoulder-joint range of motion has been shown to have a direct impact on wheelchair propulsion economy and could also be relevant for sit-skiing.

One difference in DP between standing and sitting skiers is that in sit-skiing the use of leg muscles is restricted (even if it could be possible). The rules state that the buttocks cannot be lifted from the seat. The second important difference is that in sit-skiers the poling phase is started with the hands above head level. Depending on the impairment, athletes have chosen to use different sitting positions. It has previously been shown in wheelchair propulsion that the sitting position has an impact on the force-generation capabilities by altering the athlete’s pattern of propulsion, which consequently affects the performance (Måså et al., 1992; Vandenewijck et al., 2011). The shoulder-joint range of motion has been shown to have a direct impact
on wheelchair propulsion economy, and this could be relevant also for sit-skiing. However, since the sitting positions are sport specific, the results from wheelchair studies cannot be directly extended to sit-skiing, in which there is currently a lack of published research.

Different sitting positions have been tested using non-disabled individuals and it has been seen that the “kneeling” position was the most effective position to achieve the highest velocity (Figure 11.8) and highest peak-to-peak EMG amplitude using a ski ergometer (Rapp et al., 2014). The onset of muscle activation, however, was the same in all positions and in this test economy of movement was not evaluated. The observed higher activation of abdominal muscles before starting poling suggests that core stability is one requirement to achieve the best poling performance. In another experiment (as yet unpublished data), again with non-disabled individuals, sitting position also affected skiing economy. Oxygen consumption, ventilation, blood lactate concentration, and cycle rate were significantly higher and hip range of motion lower with “knee-high” compared to “kneeling” posture at a load of 70% of maximum. This indicates that sit-skiers should if possible adapt their posture to resemble the “kneeling” posture rather than the “knee-high” posture. This finding was supported in a pilot test with one disabled athlete who could, with extra support, try the “kneeling” position. Even without any training, she was immediately able to improve her maximal skiing velocity in the

Figure 11.8  Maximum velocity at the ski ergometer in different sitting positions.
ski ergometer test. How this position would affect mechanical efficiency and skiing economy should still be tested.

**Coach’s Corner**

Comparing skiers from classes LW10 and LW11 in different sitting postures has shown that skiers using the “kneeling” posture had significantly more extensive trunk movement compared to skiers sitting in the “knee-high” posture.

**Field studies**

Measurements have also been conducted during competitions utilizing videos to analyze joint movements. Data has been published from Turin 2006 as well as from Vancouver 2010 Winter Paralympic Games (Bernardi et al., 2013; Gastaldi et al., 2012). Based on the measurements from Vancouver, which included 50 sit-ski athletes filmed during Nordic long- and middle-distance, relay, and long and short biathlon races, it has been suggested that the poling cycle for the sit-skiers should be divided into three phases: poling phase, transition phase, and recovery phase (Gastaldi et al., 2012). The poling phase starts with the maximum body and arm extension and the end is identified with the maximum velocity achieved by the sledge. Thus, in addition to active push, the early sledge acceleration is also included. The transition phase starts after the poling phase and ends with maximum elbow extension, followed by the recovery phase. This definition differs slightly from just the poling phase and recovery phase that have been used in able-bodied athletes (Holmberg et al., 2006) and requires motion analysis. Differences between classes were observed in trunk range of motion (ROM), which was greater for LW11 compared to LW10. Furthermore, when comparing the skiers from classes LW10 and LW11 in different sitting postures, it was shown that skiers using the “kneeling” posture had significantly more extensive trunk movement compared to skiers sitting in the “knee-high” posture. To examine LW10 athletes in more detail, a biomechanical model was developed and inertial forces were calculated, giving further support to the important role of the trunk in sit-skiing (Gastaldi et al., 2014).

In a study from Turin 2006 Paralympics (Bernardi et al., 2013), 29 athletes were filmed during the 15 km race and five were grouped as the best and five as the worst performers. It was shown that the better sit skiers were not only faster in both halves of the race, they also had less fatigue. In the uphill section this difference was the most pronounced. In the faster group, the speed reduction was 12.5%; whereas in the slower group, their uphill speed decreased during the race by 25.1%. This difference was mainly explained by the greater cycle-length decrease in the worse group (18.2% vs. 12.4%).

We collected data from 46 athletes competing at the Sweden World Cup race in 2013 in order to analyze cycle characteristics and joint angles (as yet unpublished data). An example of LW10 vs. LW12 in the flat part of the track shows that there was a 36° difference at maximum trunk flexion and 15° lower pole to ground angle (see Figure 11.9). These data indicate that trunk movement increases with rising classification level both in flat and in uphill, and that there is more lateral trunk movement through curves in higher classes. The “kneeling” sitting position seems to be connected to more efficient poling, with longer cycle length and more trunk movement. Whether it is also more economic in the long run is not known at present. Interestingly, the skill level within classes also influences the kinematics. At the initial poling phase, more efficient skiers have larger shoulder angles and a

**Coach’s Corner**

Despite the clear lack of research related to sit-skiing, some observations can be made. Sitting position has a clear influence on both skiing economy and power production. Due to impairment not all the athletes can sit in the same position, but instead they try to choose the position that will be optimal for them. With the current methodologies it would be possible to measure how small changes in individual sitting position influence skiing performance. The role of the trunk range of motion and stability appears to be very important and emphasis should be placed on how it could be trained. Although even less information about training is available for sit-skiers than for able-bodied skiers, in principle the same training adaptation mechanisms should apply for both groups. The training programs should, however, be planned individually, taking into account the restrictions caused by the impairment.
more forward lean position. In addition, they also have a lower pole angle at pole plant and greater lateral trunk movement, which result in enhanced sledge control.

**Future perspectives and conclusions**

In classical skiing the dominant role of DP and thus upper-body strength appears likely to be increasing even more in the future. The upper body is important also in skating skiing, allowing stronger skiers to use faster but more demanding techniques during the uphill sections. Therefore, there is a need for more strength-training studies combined with research related to fatigue simulating different race conditions (track, temperature, snow). Obtaining information, such as video analysis, during actual races is challenging, but with wireless technology more detailed information is now accessible. Another important aspect is how the proper technique can be taught to the athlete, including the proper amount of feedback and in what form it should be given. Current methodology allows instant visual feedback from video data as well
as from different biomechanical variables such as cycle characteristics, forces from skis and poles, and muscle activation. To be able to calculate the propulsive forces from poles and skis is very important in order to fully understand and optimize the skiing technique. The aim is that in the future with the help of IMU sensors using joint, pole, and ski angles, propulsive leg and pole forces can be calculated online.

All this also applies to Paralympic Nordic skiing. Methodologies used in able-bodied skiers are available, but so far have not been utilized much. Especially in Paralympic standing skiing, there is almost a total lack of scientific research. In visually impaired skiers it would be of interest to examine how the content and frequency of audio feedback are related to skiing technique and performance. For amputee skiers, how the length of the amputated limb affects skiing performance should be studied. This would be possible with the help of modeling based on the calculations obtained from non-disabled athletes. Several research groups, including our own, are currently working on modeling and calculating upper- and lower-body propulsive forces, which in the future could be utilized in amputee skiers.

Regarding performance in sit-skiing, in addition to training and fatigue studies, there is still a need for further studies on the effect of sitting position, strapping, and the role of trunk activation. Due to impairment, not all athletes can use the optimal sitting position. Therefore, sitting positions should be individually optimized. The effect of cold weather can be even more substantial for sit-ski athletes than standing athletes, in particular those with spinal cord injuries who have a smaller amount of active muscle mass producing the work. Thus, this is an important topic to address.

In sit-skiing there is also currently a need to improve the classification system. Together with several international partners and the IPC, we have been developing new tests during the past few years. The first tests with non-disabled skiers were conducted to establish what muscle groups were used in a ski ergometer and balance perturbation tests, and how sitting position affected the results, which were briefly described earlier in this chapter. Subsequently, Paralympic athletes have participated in the same test, except for the physiological measurements. Most recently an uphill (see Figure 11.10) and flat skiing test in a ski tunnel was also included in the study protocol. These data are being analyzed and will be reported in the near future.

One important challenge is to measure maximal EMG so that the EMG during skiing and balance perturbation can be normalized. To obtain maximal EMG we used isometric maximal voluntary contraction measurements with a specially constructed “force belt,” which allowed us to get data also on maximal forces. The balance perturbation test causes an involuntary movement that is different depending on the level of impairment and whether a reflex response is present or not. Based on the EMG and accelerometer data, the athletes are grouped using cluster analysis. Data from ski ergometer and ski tunnel tests are used for performance values and to verify the relationship to the perturbation test. Figure 11.11 shows the setup that was used for both ergometer and balance perturbation tests. In the balance test, the arms are hanging free on the side. There is still a need to construct a special chair that would allow for studying the effect of different sitting positions on performance in the ski ergometer and in the balance test. So far the athletes have been using their own chairs.
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Some additional force measurements to evaluate the impairment level are also warranted.

In conclusion, alongside the increasing popularity of Paralympic Nordic skiing there is a clear need to increase scientific research. By further improving the classification process, more people will be attracted to the sport. Research knowledge obtained from top-level athletes can also be utilized in teaching, in rehabilitation, and in developing injury-preventive measures for people with physical impairments. Optimizing performance in top sports is a fascinating challenge and the scientific tools to accomplish that are available for Paralympic Nordic skiing. Another important aspect, in addition to the physical improvements for the individual, is the development of equipment, training devices, and infrastructure. We are optimistic that in the future the amount of research will increase and are looking forward to cooperation with other scientists and sportspeople.

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