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ABSTRACT

Background People with disabilities often depend on assistive devices to enable activities of daily living as well as to compete in sport. Technological developments in sport can be controversial.

Objectives To review, identify and describe current technological developments in assistive devices used in the summer Paralympic Games; and to prepare for the London 2012 Games, the future challenges and the role of technology are debated.

Methods A systematic review of the peer-reviewed literature and personal observations of technological developments at the Athens (2004) and Beijing (2008) Paralympic Games was conducted.

Results Standard assistive devices can inhibit the Paralympians’ abilities to perform the strenuous activities of their sport. Although many Paralympic sports only require technology similar to their Olympic counterparts, several unique technological modifications have been made in prosthetic and wheelchair devices. Technology is essential for the Paralympic athlete, and the potential technological advantage for a Paralympian, when competing against an Olympian, is unclear.

Conclusion Technology must match the individual requirements of the athlete with the sport in order for Paralympians to safely maximise their performance. Within the ‘performance enhancement or essential for performance?’ debate, any potential increase in mechanical performance from an assistive device must be considered holistically with the compensatory consequences the disability creates. To avoid potential technology controversies at the 2012 London Olympic and Paralympic Games, the role of technology in sport must be clarified.

INTRODUCTION

Equipment such as prostheses and wheelchairs is fundamental in allowing some people with disabilities to carry out the tasks of daily living. Advances in technology underpin such assistive devices—for example, the development of the energy-storing prosthetic foot, can make a lower-limb amputee’s gait more efficient and ambulation faster. When this revolutionary prosthetic technology was specifically applied to sprinters, studies showed that running velocity was significantly increased. However, the application of this technology has been controversial, as clearly demonstrated by the much-publicised Oscar Pistorius or ‘Blade Runner’ debate before the 2008 Beijing Olympic and Paralympic Games. The skill of the athlete, coupled with this new prosthetic technology, enabled Oscar to potentially qualify in the men’s 400 m sprint in both the 2008 Olympic and Paralympic Games. In the best interest of the athlete, and to avoid potential legal problems and unwarranted issues for the next Olympic Games in London 2012, the role of technology needs to be clarified.

Under rule 144.2, the International Amateur Athletics Federation (IAAF) forbids ‘the use of any technical device incorporating springs …that provides the user with an advantage over another athlete not using such a device.’ This raises the question: Does the technology create an unfair advantage for the Paralympian when competing against able-bodied Olympic athletes? When we debate whether certain sports technologies provide an advantage over another athlete, the issue becomes clouded, as we must also consider equitable access to the technology. Consider, for example, that the Olympic marathon was won in 1960 by Abebe Bikila, an athlete from Ethiopia who ran barefoot. How much faster could Abebe have run with contemporary technology to absorb the jarring ground reaction forces and improve friction at the foot-ground interface? At the 2008 Beijing Games, some track and field athletes wore clothing that incorporate threads of Vectran fibre which, the manufacturer, Nike, claimed ‘reduce drag by 7% when compared with the 2004 outfits.’

Although not discussed in peer-reviewed literature, it is well documented in the press and sports communities that both the Olympic and Paralympic movements struggle with the role of technology in the sporting arena. For example, in 2008, Speedo launched their new LZR Racer suit amid much debate about the performance-enhancement characteristics of these new suits. The suit’s technology included strategically placed polyurethane panels to reduce drag and a corset-like structure that may help to streamline the body, although this effect is yet to be confirmed in scientific literature. At the 2008 Beijing Games, 94% of all swimming races were won by swimmers wearing the suit. A total of 108 world records were broken in 2008, and at the 2009 World Swimming Championships in Rome, another 43 world records tumbled, mostly with swimmers wearing the new controversial polyurethane suits. It is speculated that the suits create a greater advantage than the best performance-enhancing drugs, which raises the comment: ‘Who’s going to win the gold medal, the swimmer or the technician?’

Paralympic sports evolved from medical rehabilitation programmes in the 1950s. The objective of a rehabilitation programme is to regain a level of function for the client; for an athlete with a disability, the highest expression of this return to function is to compete at an elite level in the...
Paralympic Games. In the endeavour to go higher, faster and longer, athletes have found that standard devices can inhibit their sporting performance. To satisfy the demands of these elite athletes, significant new technological developments in wheelchair design and prostheses have occurred, and radical equipment designs such as the J-Leg, seated throwing chairs and racing wheelchairs have revolutionised sports-medicine thinking. Paralympic athletes compete in 18 summer sports, of which the same number are Olympic sports. The four sports unique to the Paralympics are goalball, boccia, wheelchair rugby and powerlifting. As the majority of sports within the Olympic and Paralympic Games are similar, the evolution of technological and task-specific developments has been similar in both games. For example, the development of aero bar technology in cycling has been applied to both Olympic and Paralympic cycling.

As technological advances continue to provide opportunities for improved athletic performance, an ongoing challenge for international sporting bodies will be to determine if the use of a given technology represents ‘performance enhancement’ or, rather, is ‘essential for performance.’ In a practical sense, should progressive improvements in sporting equipment, such as the J-shaped Flex-Sprint III (Cheetah) prosthetic foot that provides a more forward directed propulsion, be allowed in Paralympic and, possibly, Olympic sport? This review identifies the current technological developments within the summer sports of the Paralympic Games and discusses the role of technology.

METHODS
Standard literature searches were performed (in English) using the key words technology, sport, Olympic and Paralympic in the computerised databases PubMed, PsychINFO, ScienceDirect and Google Scholar. This review is restricted to a discussion of technology in the 18 Paralympic summer sports. The retrieved articles were screened and assessed for relevance to the biological, biomechanical and biomedical aspects of technology in Olympic and/or Paralympic sport. Personal observations of technological developments for athletes competing at the 2004 Athens and 2008 Beijing Paralympic Games were also made. In addition, specific reviews of the proceedings from key scientific congresses were conducted (eg, the 2008 (pre-Olympic) International Convention on Science, Education and Medicine in Sport).

DISCUSSION
This review comprises a brief overview of the categories of disability in Paralympic competition, followed by discussions of: the Paralympic sports that have limited specialised technological requirements as they utilise athletes’ existing assistive devices; the sports that rely heavily on specialised technology, in particular prostheses and modified wheelchairs; and the future challenges.

Classification of disabilities in Paralympic competition
As there are specific and unique biological requirements associated with particular physical disabilities, an overview of the Paralympic classification system will lend clarity to the subsequent discussion. 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; athletes with cerebral palsy, defined as having the cerebellar area of the brain affected; athletes with a spinal-cord injury; athletes with a visual impairment (perception to a visual acuity between 2/60 and 6/60, and/or a visual field of >5° and <20°); and athletes with les autres, a French phrase meaning the ‘others;’ this group comprises athletes who do not fit within one of the other disability groups but nevertheless have a permanent physical disability (eg, one femur shorter than the other, resulting in a significant difference in leg length).

Paralympic sports with limited technological requirements
In the sport of archery, the athlete that requires a wheelchair typically uses their day-chair, and the ambulant athlete who stands (eg, amputees or those with cerebral palsy) also uses their typical prosthesis or walking device. Boccia athletes also typically use their day-chairs, and limited new technology is required. In cycling, athletes with a physical impairment (eg, amputees, les autres and those with cerebral palsy) may have modifications to their bicycles to accommodate specific disabilities. For example, if the cyclist has an arm disability, the aero-bars may be modified. Athletes with a visual impairment ride a tandem bicycle with a sighted guide at the front. The development of the tandem cycle is unique to Paralympic cycling, and the technological developments for the cyclist are often governed by the creative skills of the cycling technicians associated with the cyclist. Equestrian athletes have no unique technological requirements, apart from some minor modifications to their tack. There are two categories in the sport of football, 5-a-side for athletes with a visual impairment and 7-a-side for athletes with cerebral palsy. In the 5-a-side game, the only modification is a ball with a noise-making device for sound location. As this is internationally consistent for all players, the technology is considered essential for performance. In the 7-a-side game, there are no technical modifications, but there are some rule modifications; for example, one-handed throw-ins are permitted, as play under the existing rule would not be physically possible for some athletes. The sport of goalball is open to visually impaired athletes, and to provide an even playing field all players must wear black-out goggles. As with other sports for the visually impaired, the ball is equipped with a noise-making device to allow sound location. Again, the technology is considered essential for performance. In judo, athletes are grouped into weight categories in the same way as able-bodied judo athletes, and no technology is required for this sport. Powerlifting also groups athletes into weight categories, and no technology is required for this sport. In Paralympic rowing, as in Olympic rowing, the hull of the boat is the same for all competitors. However, the seat in a Paralympic boat may be modified as required by the athlete’s individual disability. For example, athletes with spinal-cord injuries may require modified seats that provide postural support. Similarly, in sailing, athletes also sail identical boats, and so the technology is considered minimal and essential. Shooting is open to athletes with physical disabilities, and no technological differences exist between the Paralympic and Olympic versions of this sport. Paralympic swimming generally follows the International Swimming Federation (FINA) rules, with some essential modifications, such as allowing one-handed touches for swimmers who can only extend one hand out in front. In some cases, the additional ‘technology’ required is very simple; figure 1 shows a swimmer with no arms using his teeth to hold onto the towel/rope for the race start. As in Olympic swimming, athletes wear only a swimsuit, goggles and cap, and Paralympic athletes are not permitted to use any prostheses or assistive devices while in the
water. Currently, the most controversial issue in swimming is related to advances in the manufacture of swimsuits, which has provoked heated discussion on the technological ethics of the sport. The first modern Olympic swimming races were held at the 1896 games, but it was 80 years later in 1976 that swimming goggles were first allowed. Will the current swimsuit technology be considered ‘typical’ in 80 years’ time? Perhaps the most important factor is equity of access to the new swimsuits, as they are very expensive and need frequent replacing.

Table tennis is open to athletes with a physical disability, and athletes who are ambulatory typically use their standard assistive devices. For athletes in wheelchairs, the distances to travel and demands to change direction are small, and so the athletes tend to use their day-chairs and require no special technology in this sport. Paralympic volleyball follows the same rules as Olympic volleyball and requires no novel technology. Wheelchair fencing is open to athletes with a physical disability and the athletes use their day-chairs.

**Technology specific to Paralympic sports: prostheses and wheelchairs**

There are two key areas in which technology has a major influence on performance in Paralympic sports, namely specialised prostheses and wheelchairs. The influence of this technology on the remaining Paralympic sports of athletics, wheelchair basketball, wheelchair rugby and wheelchair tennis will now be discussed.

**Specialised prostheses**

Lower-limb amputees rely on the technical attributes of their prosthetic limbs to ambulate, and the specifications of these components have varied considerably in recent years. For the unique requirements within the three field events of shot-put, javelin and discus, athletes may have three sport-specific prostheses built, in addition to their day-prosthesis. For example, the need for support during the rotation phase of the shot-put or discus requires different properties in a prosthetic device when compared with the need for stability and linear velocity during the run-in when throwing a javelin. The specific rotation requirements for performing the shot-put and discus events have resulted in the development of the J-Leg technology. This prosthesis essentially has a fixed knee unit to provide stability throughout the rotation, and an energy-storing foot has been mounted at 180° to the standard orientation (ie, toe facing posteriorly). This alignment facilitates extra stability in rotation, and the energy-releasing characteristics of the foot also provide the desired ground push off before the throw release. However, the question is raised, ‘Does this technology enhance performance, or is it essential for performance?’

Ambulatory amputee runners have benefited considerably from advances in prosthetic technology. In the IAAF assessment of Oscar Pistorius, one of the striking biomechanical findings was that the prosthetic limbs developed an energy loss of about 9% during the stance phase, compared with 41% in the human ankle joint. Based on the outcome of this review, the athlete was initially considered to have an unfair advantage over able-bodied competitors, and thus Oscar was not eligible to compete in the Olympic Games. After a subsequent appeal, however, Oscar was allowed to compete, and although he had previously achieved the qualification time, he was not able to repeat this performance after the appeal. The mechanical efficiency achieved by some of the current prosthetic devices is further demonstrated when considering the jumps events for ambulatory runners (eg, the long-jump). Within the previous Paralympiad, there has been a shift in jumping technique, with transtibial and transfemoral amputees now making the touchdown step with their prosthetic rather than their anatomical limb. Athletes have found that their prosthetic limbs can absorb and release the ground reaction force more effectively than their anatomical limbs, thus generating higher velocities at takeoff. The athletes depend on their prostheses in order to run, and so the prostheses are essential for performance; however, based on the mechanical analysis alone, these same aids could be considered performance enhancement.

A factor not considered in a laboratory test of mechanical efficiency is the influence of the stump–socket interface on the prosthesis. This connection is critical to the operation of the prosthesis, as any movement of the amputated stump will subsequently swing the prosthetic limb. Furthermore, once the prosthesis makes contact with the ground, it is the stump–socket interface that transmits the load-bearing ground reaction force back to the amputee. The effectiveness of this interface, and the ensuing proprioception, is therefore fundamental for the overall performance of the amputee. Figure 2 illustrates the differences in technology and the important connection between residual stump and prosthetic device. Without an effective interface to control the prosthetic device, the potential mechanically efficiency of the technology may not be translated into reality. As a biological structure, the anatomical stump is influenced by factors such as changes in altitude and local climatic conditions of humidity at the performance environment, which could be different from the athlete’s native environment. These factors can influence the volume of the stump, and as the stump is contained in a volume-specific socket, any changes will naturally alter the stump–socket contact points. This change in volume and subsequent load-transfer contact point is also influenced by the altered activities of daily living that athletes may experience while living in the Paralympic village. For example, the immense size of the village can dramatically increase the number of daily steps taken, although no studies to date have published this step count. As this critical issue remains unquantified and unaddressed, the potential prosthetic technology performance enhancement between Paralympic and Olympic athletes remains unclear.

Finally, when considering the effectiveness of prosthetic technology in sport, the not-so-obvious compensatory factors need to be considered. At first glance, the impact of a lower-limb amputation seems to be confined to the lower limb.

**Figure 1** Swimmer’s start with simple technology.
However, the skeletal image of an amputee identifies several compensatory factors (figure 3). The amputation alters the orientation of the pelvis. As the pelvis is connected to the vertebral column, the change in pelvic angle causes a scoliosis of the spine. The altered orientation of the vertebral column in the cervical region then causes the shoulders to change alignment, as well as the orientation of the skull to be altered. Thus, the ‘compensatory’ mechanisms resulting from the amputation can have far-reaching consequences on the functional ability of the athlete. This phenomenon further supports the need to evaluate the athlete and the technology in a holistic manner before forming the view that a particular technology enhances performance.

Specialised wheelchairs
The traditional wheelchair (day-chair) design consists of two larger wheels at the rear of the chair to allow forward propulsion via the push-rims, and two small smaller wheels at the front of the chair to provide stability. The steering of the day-chair is controlled by manipulating the rear wheels, either braking or propelling more on one side to change direction. The unique requirements of sporting use, however, have modified this conventional design dramatically. Due to the need for rapid acceleration and to change direction suddenly in wheelchair basketball and wheelchair tennis, many chairs now incorporate a fifth wheel at the back, preventing the chair from flipping backwards during play. In addition, in the high-impact sport of wheelchair rugby, the chairs are also fitted with reinforced front and side bumper guards that have special ‘hooks’ to trap opposition players. Players in these sports must often move quickly and change direction rapidly while carrying or holding balls or rackets, as shown in figure 4. To accommodate this requirement, the camber of the rear wheels is increased to facilitate a quicker ‘grab’ of the rear wheel. This increased camber also improves hand protection when two chairs collide on the court and improves turn velocity.

For athletes who compete on the track or road, racing wheelchairs resemble a cross between a wheelchair and a bicycle. As with the sport-specific prosthetic limbs, there are sport-specific racing wheelchairs that are lighter, will track in a straight line and are aerodynamically designed to enhance track performance. For straight-line racing on the track or road, the racing chair has evolved with an extra long-wheel base and a single large front wheel. The push-rims are considerably smaller on the racing chair, as the biomechanics of this configuration requires less arm movement but greater push. As a wheelchair racer will generally only compete against fellow wheelchair racers, the issue of performance enhancement is a moot point, as the technology is essential for performance. However, the equity of access to this wheelchair technology must be addressed, particularly in light of future challenges.

Future challenges
Despite the initial scepticism about technological advantage in the Oscar Pistorius ‘blade-runner’ case, the subsequent eligibility ruling should be applauded. The technological development was primarily attempting to restore loss of function in the Paralympic athlete. Given that a ‘grey area’ remains regarding how well an athlete is able to transfer any potential mechanical advantage into a real advantage, the sporting ‘benefit of the doubt’ should probably fall in favour of the technology being essential for performance, rather than performance-enhancing. The evolution of assistive technology to enhance sports performance, or just to assist people with a disability to conduct the activities of daily living, is long overdue. The increase in the mechanical performance of any sports assistive device must always be considered together with the compensatory consequences of disability within the athlete. More applied research is required to clarify the true advantage, if any, of specialised assistive devices for athletes with a disability in competition with able-bodied athletes. The challenge for researchers will be to effectively ‘match’ the technology with the athletes’ requirements. Future developments in technology must be considered in conjunction with a holistic assessment of the athlete’s performance before any decisions are made regarding illegal enhancement of performance. As such, given the current limitations on assessment...
Future technological developments will have far-reaching implications for Paralympic athletes. The development of assistive devices that are more effective in performing daily tasks but also enable increased performance in the competition arena. If the technology needs to be openly debated and clarified.

An understandable temptation for researchers is to only focus on the assistive devices that are more likely to be funded through research grants. As the majority of people with disabilities are aged, the development of assistive devices has naturally focused on this market. Paralympic athletes have created a new, albeit small, market. Not only are these athletes significantly younger than the traditional aged person with a disability, but they are also highly active and, as such, place far greater loads on the assistive devices. When considering the market drivers in industries such as the automobile manufacturing industry, most of the technological developments and improvements in design that we all enjoy in the family car have originated in the sport of motor racing. A similar scenario can be applied to the future development of assistive technology, with active Paralympic athletes testing the devices under extreme conditions before mass production for the larger rehabilitation market. This new market demand, in the long term, will result in a better understanding of the relationship between human biology, the biomechanical aspects of disability, the activities to be performed, and the biomechanics of the assistive devices. However, there is still some way to go, as currently the market demand for adaptive technology is overwhelmingly biased towards an aged population.

At both the Olympics and the Paralympics, authorities must fundamentally strive to provide an even playing field, which includes ensuring equity of access to technology. Developed countries have access to both the materials and the knowledge behind the technology, and therefore can modify the technology to meet their specific requirements. However, the situation is more problematic for athletes in developing countries. Future technological developments will have far-reaching effects on Paralympic athletes: their new assistive anatomy with its higher level of functionality will not only lead to improved efficiency in performing daily tasks but also enable more effective performance in the competition arena. If the guidelines on the use of novel technology are too restrictive, this will stifle future progress in technological development; alternatively, in a free-for-all environment, providing an even playing field for all will be a challenge. One solution could be the development of two ‘categories’ of competition in those sports that rely on technology. In the first category, the characteristics of the assistive devices in terms of mass, length, etc would be specified, as in Olympic rowing, thus providing an even playing field. The second category would contain no restrictions for assistive devices and would encourage open creativity for researchers and athletes alike. This scenario may place extra strain on the already crowded competition programme at the Paralympics.

Understanding how and why the human body moves and, importantly, the factors that limit or enhance our capacity to move, is critical to any sporting performance, but especially so for athletes with disabilities. What is also needed is the application of the tremendous technological developments in various spheres of human endeavour (eg, exploration in space, manufacturing and medical science) to the challenges faced by Paralympic athletes. The wheel does not need reinventing; rather, we need to look at what has already been developed and then determine how to apply this knowledge to the problem at hand. When this lateral-thinking approach is applied, the future will really be a better place for Paralympians and all those with disabilities alike.

**CONCLUSION**

Although there have been improvements in the mechanical function of some assistive devices, the question of ‘performance enhancement or essential for performance?’ is surely still heavily weighted in favour of essential for performance. The challenge for the future is to ensure that technological advances are matched to the functional needs of the athletes, and there is equity of access.

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**What is already known about this topic**

- Prosthetic and wheelchair technology are fundamental for some people with disabilities to carry out activities of daily living.
- Paralympians have found that standard prosthetic and wheelchair devices can be unsafe and inhibit their sporting performance.
- Technological advances in sport can be controversial.

**What this study adds**

- The current technological developments within the Paralympic Games are described and the role of technology defined.
- Technology is essential for the Paralympian in their activities of daily living through to when they compete on the international stage.
- In the best interest of the athlete and to avoid potential issues for the London 2012 Games, the role of technology needs to be openly debated and clarified.
Provenance and peer review  Not commissioned; externally peer reviewed.

Detail has been removed from this case description/these case descriptions to ensure anonymity. The editors and reviewers have seen the detailed information available and are satisfied that the information backs up the case the authors are making.

REFERENCES