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Shifting boundaries in sports technology and disability: equal rights or unfair advantage in the case of Oscar Pistorius?

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In Paralympic sports, athletes often depend on some form of equipment to enable activities of daily living, including the ability to participate in sport. Determining precisely when technology assists sports performance and when it transforms or distorts them presents a philosophical and ethical dilemma. We raise the conceptual problem of line-drawing between promoting rights of access to equipment that provide equal opportunity while proscribing 'boosting' technology where athletes with a disability are afforded an unfair advantage. We set out a multidisciplinary analysis regarding the Olympic eligibility for Oscar Pistorius, the double-amputee world record holder, who runs with transtibial prostheses. We present scientific data comparing the prosthesis with an anatomical limb, and then contextualise the issue of shifting the boundaries of sports technology and disability to inform better policy-making in relation to the athlete–technology eligibility debate.

Keywords: Paralympics; sports technology; ethics; Olympic eligibility

Points of interest

- People with a disability often rely on some form of technology to allow activities of daily living, and to participate in sport.
- The boundary at which technology is essential for a person with a disability to perform in their sport and when it creates an unfair advantage is unclear.
- Scientific data comparing the function of a prosthetic limb with an anatomical limb are presented.
- The research recommends, to avoid potential controversies at the 2012 London Olympic and Paralympic Games and beyond, the sports technology and disability boundary be clearly defined.

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Introduction

Much ink has been spilt over Oscar Pistorius, or 'Blade Runner', the South African Paralympic athlete who attempted to make the transition between Paralympic and Olympic Games participation. The debate raged prior to the 2008 Beijing Olympic and Paralympic Games and has scarcely abated in legal, philosophical and scientific journals (Burkett, Potthast, and Mcnamee 2008; Edwards 2008; Jones and Wilson, 2009; Lippi and Mattiuzzi 2008; Swartz and Watermeyer 2008; van Hilvoorde and Landeweerd 2008). At the heart of the debate is the issue of where does the boundary of sports technology and people with a disability lie? As an athlete with a disability Oscar Pistorius a bilateral transtibial amputee who runs with highly advanced prosthetic legs. The combined skill, speed and strength of Oscar Pistorius, coupled with this new prosthetic technology, were sufficient to make Oscar Pistorius a serious contender to represent his country in the men's 400 m sprint for not merely the 2008 Paralympic Games (where he was ranked number one) but also the Olympic Games. However, rule 144.2 of the International Association of Athletics Federations (IAAF) forbids 'the use of any technical device incorporating springs, wheels or any other element that provides the user with an advantage over another athlete not using such a device' (IAAF 2009). The question of whether Oscar Pistorius was in contravention to this rule was raised and caused considerable controversy. Both empirical data and ethical debate are necessary to determine an answer to this boundary or line-drawing problem, and to determine whether the technological assistance his performance depends upon merely neutralises his disability and makes competition more equitable, or indeed whether it gives him an unfair advantage.

The idea that athletes can utilise technology in ways that are ethically problematic is not without precedent (Harris 2010; Magdalinski 2008). Typically, although not always, the ethical issue of providing good contests is framed in terms of fairness or of unfairness (Loland 2002). In 1960 the Olympic marathon was won by an athlete, Abebe Bikila, who ran bare foot without the 'shock absorbing technology' of a running shoe to modulate the typical three-times body load ground reaction forces, or to provide suitable friction between the foot–ground interface. The advantage gained by other athletes was not unfair since Bikele *chose* not to run with running shoes, and athletes broke no rules when doing so. Almost 40 years later Usain Bolt set a world record of 9.58 s in the 100 m final of the 2009 World Championships in shoes uniquely designed for him by Nike. Here, arguably, access to unique technology is not distributed fairly, although again no rule is being broken. When competing in Rome 2007 with prosthetic technology, Oscar Pistorius's second 100 m split time was measured at 10.8 s, or an average running speed of 9.25 m/s. Despite his disability this running velocity is close to the maximum running speed of an elite able-bodied 400 m sprinter.

Technology is thought of as a technical means or instrument utilised to pursue chosen ends. Under this view, technology is ethically neutral. It is neither good nor bad in itself. Rather, what matters is the end or purpose to which the technology is merely the means. While equipment such as a prosthesis or a wheelchair are fundamental for some persons with a disability to carry out their daily living (Haisma et al. 2006; Pasquina et al. 2006), advances in this technology, such as an energy-storing prosthetic foot, can make a lower limb amputee's gait faster and more efficient (Brodtkorb et al. 2008; Nolan and Lees 2000). In contrast to the ethically neutral conception of technology, however, a stronger line of criticism is found in European writers who have made problematic this assumption. Heidegger (1977) also notes more fundamental criticisms of technology as ideology where technology, far from being the hand-maiden of man, comes full circle to be its master. This criticism runs through much social and political theorising from the 1960s onwards (Foucault 1988; Habermas 2003; Marcuse 1964), where technology is sometimes seen to dominate its users by creating dependency and distorting human relations.

Many Paralympians experience a greater dependence upon technology if they are to compete at the highest level in their chosen sport. Not every athlete, however, has their career choices played out in the glare of the international media. It is fair to say that the issue of Oscar Pistorius's eligibility to the Olympic Games brings into focus a range of economic, ethical, political, scientific and sociological issues, some of which are beyond the scope of the present work. Nevertheless, some considerations of these contextual factors are necessary if a balanced and holistic judgement about whether Oscar Pistorius is to be viewed as intelligently utilising technology or gaining an unfair competitive advantage over his competitors is to be achieved.

It is true that Oscar Pistorius cuts an ambiguous figure (van Hilvoorde and Landeweerd 2008). Quite how we are to view Oscar Pistorius, without making positive or negative ad *hominem* remarks, is not a simple matter. Oscar Pistorius might be viewed as: an athlete attempting to achieve his potential at the 400 m sprint; a vanguard figure, challenging the deficit model of disability; someone whose performative self challenges the borders of human identity and technology; a sub-elite athlete attempting to break into the lucrative world of elite commercialised sports via technological assistance; or an athlete using unfair means to compete at the Olympics. These options are not exclusive. Indeed, several of them may be true at one and the same time. Moreover, the decisions about technology and sport are complex and must be based on a combination of scientific data and philosophical arguments pertaining to the nature of the challenge (articulated by the rules of every sport) and ethical ones regarding the un/fairness of the contest for victory therein. The aim of this article is to marshal relevant biomechanical analyses of Oscar Pistorius's (and other elite athlete's) running gait in the context of more general philosophical arguments pertaining to disability, technology, and sport. This knowledge can be used to define any necessary shift in the current policy boundaries of disability, technology, and sport. We turn first to the empirical analysis.

Methods

Participants

To determine the potential un/fairness of the contribution Oscar Pistorius's prosthetic technology offers, some complex measurements are necessary. The biomechanical kinematic and kinetic data were obtained from one athlete with a bilateral transtibial amputation (body mass: 83.3 kg; body height: 1.85 m) who competed at the World and Paralympic Games, and five similar able-bodied 400 m sprinters (average body mass: 78.6 ± 7.9 kg; average body height: 1.88 ± 0.05 m). All participants provided written informed consent for the human research ethics approval. Among the sample, the personal best time for 400 m was 46.3 s (for athlete with amputation), and for the able-bodied 400 m sprinters was 48.3 ± 1.17 s (range: 46.50–49.26 s). The anthropometric data of the participants who volunteered for the study are summarised in Table 1. Data for the athlete with an amputation are taken while wearing the dedicated sprinting prostheses (Cheetah, Össur, Iceland).

Data collection and data analysis

The athletes were asked to performed maximal and submaximal sprints over 50 and 70 m on a 100 m indoor track. The indoor track was equipped with four force plates (9287B; Kistler AG, Winterthur, Switzerland) and a set of 12 infrared high-speed cameras (Vicon 624; Vicon Motion Systems, Oxford, UK). That arrangement allowed for measuring the ground reaction forces (forces acting from the ground onto the athletes' centre of gravity) and the kinematics of the lower extremity (motion of the three leg segments thigh, shank and foot) during sprinting with maximal individual running speeds. Based on a three-segment rigid body model of the lower extremity (Stafilidis and Arampatzis, 2007), joint moments of the hip, knee and ankle as well as joint work (i.e. energy, which is absorbed and generated) done at ankle and knee were calculated by means of inverse dynamics. A more detailed description of the measurement methods can be found elsewhere (Brüggemann et al. 2008).

Results

The sprinting mechanics of the double transtibial amputee athlete show substantial differences in several parameters compared with the able-bodied control athletes. The amputee sprinter flexed his knee joint clearly less during stance and therefore the range of motion of the transtibial amputee is smaller than that of the control athletes (Table 2). The maximal external knee flexion moment of the amputee runner was clearly lower (1.2 ± 1.7 Nm/kg) than that of the controls (4.7 ± 1.1 Nm/kg), which holds also true for the external knee extension moment (0.8 ± 0.3 Nm/kg versus 1.6 ± 0.9 Nm/kg). The opposite behaviour emerges, however, at the ankle joint. The maximum external moment at the (prosthetic) ankle joint of the amputee was about 50% higher than in the able-bodied controls (Table 2). Similar group differences were found regarding the contribution of mechanical energetic at the knee and ankle joint. In the first part of the stance phase, the artificial ankle joint (i.e. prosthesis keel) of the amputee absorbed 1.16 ± 0.2 J/kg in the prosthetic ankle joint. More than 90% of that energy was returned in the second half of the stance phase (Table 2). The control subjects absorbed remarkably less energy in the ankle joint in the first part of the stance phase (0.78 ± 0.13 J/kg) and in addition they generated only 53% of that in the second part (Figure 1 and Table 2). The knee joint of the impaired athlete contributed much less. It both absorbed and generated

Table 1. Anthropometric data and 400 m times for the double-amputee sprinter and the control athletes.

	Double amputee	Control
Body mass (kg)	83.3	78.6 ± 8
Standing height (cm)	185	187.8 ± 5.7
Age (years)	21	22 ± 2
400 m personal best (s)	46.34	48.53 ± 1.2

Table 2. Mean values and standard deviations of selected mechanical variables for the double-amputee sprinter and healthy controls.

	Double amputee	Control
Knee flexion (degrees)	4.9 ± 4.4	11.6 ± 3.1
External knee flexion moment (Nm/kg)	1.2 ± 1.7	4.7 ± 1.1
External ankle flexion moment (Nm/kg)	6.2 ± 0.5	4.1 ± 0.2
Negative work ankle (J/kg)	1.16 ± 0.2	0.78 ± 0.13
Positive work ankle (J/kg)	1.06 ± 0.16	0.41 ± 0.21
Negative work knee (J/kg)	0.02 ± 0.04	0.33 ± 0.18
Positive work knee (J/kg)	0.03 ± 0.05	0.13 ± 0.16
GRF breaking impulse (N/kg*s)	0.18 ± 0.02	0.25 ± 0.05
GRF propulsive (N/kg*s)	0.20 ± 0.04	0.28 ± 0.02
GRF impulse vertical (N/kg*s)	2.1 ± 0.3	2.5 ± 0.1

All values differed significantly between groups. GRF, ground reaction force.

below 0.1 J/kg. In contrast, the able-bodied sprinters absorbed 0.33 ± 18 J/kg and generated 0.13 ± 0.16 J/kg at the knee joint (Figure 2 and Table 2). The amputee sprinter generated lower peaks in the vertical component of the ground reaction force as well as smaller negative and positive peaks in the anterior posterior component. The related vertical (2.14 ± 0.31 Ns/kg versus 2.46 ± 0.11 Ns/kg), breaking (0.18 ± 0.02 Ns/kg versus 0.25 ± 0.05 Ns/kg) and propulsive impulses (0.20 ± 0.04 Ns/kg versus 0.28 ± 0.02 Ns/kg) were also lower for the amputee sprinter.

Discussion

One of the most striking findings of this study was the big difference in distribution of energy contribution over the joints of the lower extremity between able-bodied and double-amputee sprinters. The relative contribution of mechanical work is much more evenly distributed in the able-bodied athletes, where the knee joint contributes much more in comparison with the amputee sprinter (Figure 2). In double-amputee

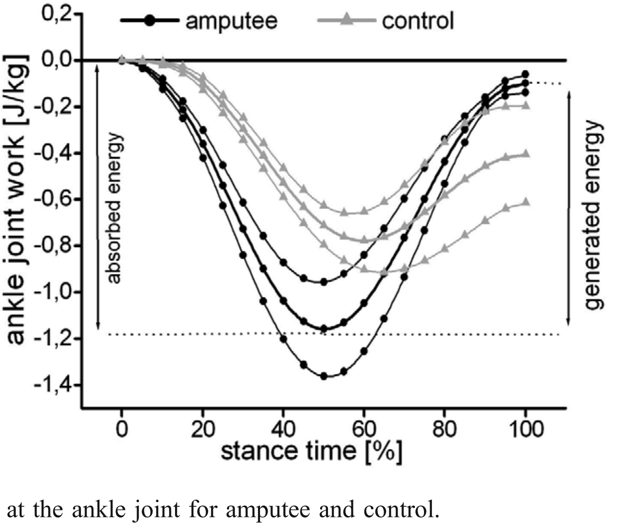

Figure 1. Work at the ankle joint for amputee and control.

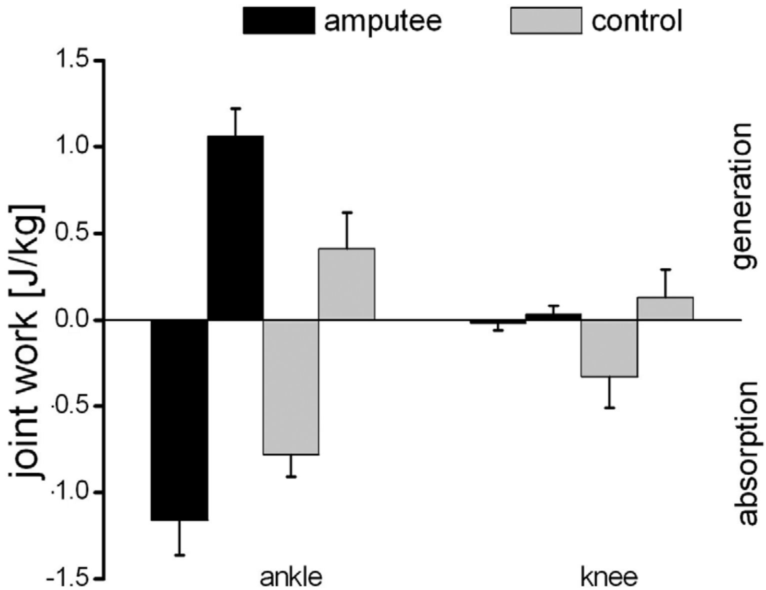

Figure 2. Ankle and knee joint work for amputee and control.

sprinting the majority of mechanical work of the lower extremity is done in the prosthetic ankle, the knee joint contributes very little (Figure 2). In addition, the prosthetic ankle is exceptionally efficient. The joint behaves almost ideally in terms of elasticity, dissipating only 5–8% of the stored energy. In the ankle joint of the able-bodied athletes, a much higher percentage of the absorbed energy (46%) is not returned. This means that the double-amputee sprinter can, once he has a certain level of velocity and therefore kinetic energy, store a considerable amount of energy in his prosthesis during the first part of the stance phase. In the second part of the stance about 95% of this energy is returned. This locomotion strategy, which could be characterised as an almost ideal elastic spring-like bouncing, is entirely different from the locomotion strategy of the able-bodied sprinters. The able-bodied athletes generate energy at ankle and knee joint through muscular work. This is also expressed by the much higher external knee extension moments, which have to be counteracted by higher forces mainly generated by knee extensor muscles. In accordance with this, the knee flexion during stance is higher in the able-bodied sprinters. The different locomotion strategy of the double-amputee sprinter in comparison with able-bodied counterparts leads to reduced vertical impulses of the ground reaction force, which indicates a smaller vertical movement of his centre of gravity. It also allows sprinting with a reduced breaking impulse in the beginning of the stance. Therefore, a reduced acceleration impulse in the second part of the stance phase is sufficient to stay on constant sprinting velocity. It can be stated that, related to the lower extremity and related to the centre of gravity, the sprinting mechanics of the double-amputee sprinter is entirely different from that of the able-bodied sprinters. This was also concluded by other researchers (Van den Bogert and Ackermann 2009; Weyand et al. 2009). In addition, using a dynamic optimisation approach, van den Bogert and Ackermann (2009) found that sprinting with the dedicated sprinting prosthesis might have the potential to change the movement pattern even more in order to enhance performance. This kind of locomotion, however, might be difficult to control.

Contextualising the data in an historical, philosophical and ethical frame

We should not think of Oscar Pistorius's case as unique. Elite athletes with a disability have participated in past Olympic Games. Liz Hartel (postpolio) won a silver medal in the equestrian dressage at the 1952 Olympics; and Jeff Float, a deaf swimmer, won a gold medal in swimming at the 1984 Los Angeles Games (DePauw 1988). Yet these athletes did not appear to employ technologies that offered an unfair advantage despite their challenging negative stereotypes of persons with disabilities. Somewhat more controversially, a wheelchair archer, Neroli Fairhall, also competed in the 1984 Olympic Games. Her disability became an issue, however, when her alleged stability advantage was questioned by traditional upright archers. Since then the issue of cross-participation has become litigious.

A recent, more high-profile, case arose when professional American golfer Casey Martin won the right to play on the highly lucrative US Professional Golf Association tour (Pickering-Francis 2007). Martin required the use of a buggy (motorised cart) to move between shots. The US Professional Golf Association, in a move similar to the International Olympic Committee's first response to Oscar Pistorius, argued that this gave him an unfair advantage. It was argued that Martin did not have to undergo the same physical test as able-bodied golfers and therefore would be less fatigued and therefore capable of maintaining higher levels of motor skill unfairly. Interestingly, with the use of equal opportunities labour legislation, in 2001 the Supreme Court in the USA held, by seven votes to two, Casey's legal right to use the golf cart between shots. It was argued that 'these mandates require reasonable accommodations or modifications in policies, practices or procedures' (Friedman and Norman 2009). Whether or not a European Court would have arrived at the same conclusion is a moot point, since the European Union has been mindful of the rather unusual nature of sports as an employment practice (Parrish and Miettinen 2008).

It is also important to stress that the legal ruling need not be synonymous with an ethical judgement. Indeed one of the first lessons in jurisprudence relates to the principle that the law is neither moral nor immoral, but rather amoral. Along such lines it might be argued that the use of buggy was against the spirit of the sport, and offering an unfair advantage, despite the fact that Martin has a legal right to use it as a necessary part of his occupation (or, to use an older parlance, a tool of his trade). It is noteworthy that the World Anti Doping Agency uses this as one of three criteria, two of which must be present for a practice or product to be considered to be banned. In the case of doping the other criteria are: performance enhancing; and (potentially) harmful to health. It has not been lost on commentators that the 'prosthetic blades' satisfy two of the criteria and thus might be considered a candidate for the banned list.

These cases, highlighted by various high-profile media and discussed across the range of scientific disciplines, have raised the awareness of how preconceived ideas of 'ability' and 'disability' – often following what is (perhaps too) loosely called '*the* medical model' – need to be understood in a more critical light. In some quarters a bias has been perceived against a more horizontal understanding of plural abilities rather than the traditional deficit model of disability dominant in medicine and also sports medicine. This bias is sometimes referred to as 'ableism' (Wolbring 2010). Even for disability scholars, however, the technologies may represent a double-edged sword. They shine a light on disabled athletes' struggles for acceptance, status and sometimes (sexualised) adulation (Gard and Fitzgerald 2008). Yet they can also have the effect of localising public attention on the rarefied elite level of participation and reduce an ethically complex array of issues to just one: fair eligibility or entitlement. Ironically, then, one potential problem associated with Oscar Pistorius's high-profile test case is that it can narrow the lens of ethical debate to issues of eligibility and lead to a continued disavowal, once that particular issue is settled. We note, therefore, that although we intend to focus on the conceptual and empirical issue of running gait, and the specific issue of equity, we do not suggest that these are the only interesting or worthwhile issues that are raised by his case.

Returning to Oscar Pistorius's case specifically, it must be noted that lower-limb amputees rely heavily on the technical attributes of their prosthetic limb and the specifications of these components have varied considerably in recent years (Camporesi 2008). Ambulant amputee runners have benefited considerably from the advances in prosthetic technology. In the assessment of Oscar Pistorius's case, the IAAF review noted that one of the striking biomechanical factors was the prosthetic limbs developed a energy loss of around 9% during the stance phase, compared with the 41% in the human ankle joint (Fuss 2008). This efficiency differential is highly significant in performance terms.

Based on the outcome of this review the athlete and his prostheses were initially considered to have an unfair advantage over his able-bodied competitors, and he was not eligible to compete in the Olympic Games. Following a subsequent appeal the athlete was allowed to compete, and, although he had previously achieved the qualification time, was not able to repeat this performance following the appeal. It remains a moot question, however, whether aside from his technical efficiency Oscar Pistorius should have been permitted access to Olympic participation. We now discuss the conceptual and ethical issues raised.

Oscar Pistorius's eligibility: conceptual and ethical issues

In this section we focus on three important issues regarding the eligibility of this Paralympic champion to participate in the Olympics, which have wider ramifications for able-bodied sports and their participation criteria. First, it is necessary to offer a clear account of the nature of running in order to determine whether certain technologically-assisted performances achieve or even undermine it (Edwards 2008). Secondly, it is a significant and serious question as to whether the introduction of prosthetic technology introduces a logical slippery slope (McNamee 2008) to other enhancements that cannot be rejected once Oscar Pistorius's blades are accepted as a justified means towards the goals of his sport. Thirdly, there is the issue of equity or social justice: is access to this technology sufficiently broadly distributed so that all athletes with relevantly similar abilities can fulfil or exploit their potential by their use?

The issue of setting of precedents in the use of technology is a difficult one. One clear duty of sports regulatory bodies is to articulate the nature of the sports contest in order to determine whether a given technology proposed usurps it. Is what Oscar Pistorius does really running (Edwards 2008)? This is not a simple empirical issue, to be settled by biomechanical analysis alone. Rather we must dispute and decide what gait constitutes running. That is to say we must determine what 'running' means. Is the mode of Oscar Pistorius's movement (and other athletes with a disability who use similar prostheses) conceptually distinct? Is it a high-velocity/cadence form of bounding? Can we set levels of energy or mechanical efficiency that can help us to distinguish the two? Secondly, if a phenomenally efficient bounding prosthetic device could be created that would allow the 100 m sprint to be completed in three of four giant strides then would one expect that technology to be banned? Clearly Oscar Pistorius's case is not so extreme, despite the exceptionally high levels of energy return given by the blades, but it does represent an important step in that direction. Is it absolutely clear that a line may logically be drawn to distinguish the two. Does commitment to use this highly efficient technology mean that no rational case can be made to allow further developments in efficiency or can an objective and precise measure be established that is not the product of bias or prejudice? Thus we must ask, if we accept the prosthetic technology utilised, whether we have set ourselves on a slippery slope where we cannot in principle distinguish this borderline technology from others we would definitely want to avoid.

Thirdly, there is the issue of justice in (disability) sports. At all levels of sport, not merely the rarefied cases of the Olympics or Paralympics, sports are essentially about equality of opportunity (Loland 2002). This is necessary in order to ensure that all competitors share the same test (Kretchmar 1975). The Latin root of the concept of contest reveals this sense of coming together to test oneself and the other. Recently the issue of equity in the context of technology has become a hotly contested field not only in social scientific literature (Magdalinski 2008), but also in sports communities themselves. In the run up to the 2009 Swimming World Championships a number of swimmers used the media to voice their disquiet over the hyper-efficiency of certain swimsuits (Wolbring 2010). In their view, swimsuit technology far from being a neutral means to the end or goal of athletic excellence has distorted the nature of the activity itself. Rather like Formula 1 racing, the argument goes, it is the best technologies that are having an unethical effect on the outcome of the contest. FINA, the international sports federation, has agreed to ban the technology on the grounds of its distorting effects in relation to the traditional standards of swimming excellence. Might the International Paralympic Committee (IPC) take this as a precedent to follow in order to forestall the potentially distortive effects of prosthetic technology on athletics?

Irrespective of the IPC's future policy stance, it is important to note that this is a dispute is between competitors from advanced countries. In contrast, one significant feature of Oscar Pistorius's case is that it raises issues of equity beyond the western technologically advanced world. Developed countries must have access to both the materials and the knowledge behind the technology and therefore can modify the technology to meet their specific requirements if competitions are to satisfy fully the conditions of fair play so central to the health and future of sports. These developments may have far-reaching effects on the Paralympic athlete. Not only will they be 'more functionally efficient' with their new assistive anatomy, but this new level of functionality can lead to an improved efficiency in daily tasks through to a more effective performance in the competition arena. These conditions of cultural inequality represent an agenda that sports governing bodies have tended to shy away from. They have preserved their policy efforts more narrowly on in-contest rules and auxiliary rules regarding how athletes may prepare themselves (such as the production of a global list of banned doping products or processes). This structural deficit may be borne in mind as a background condition, or context, to the final judgement on whether the technology used by Oscar Pistorius (and others) renders so significant an unfair advantage that he should be rendered ineligible to participate in the Olympic Games.

It seems plausible, at the very least, to agree that the advantage given to Oscar Pistorius by his blades is significant in terms of efficiency. Determining precisely what levels of efficiency of efficiency ought to be permitted while preserving conditions of fairness will probably vary from contest to contest, so that running events might well use one set of conditions, while throwing or jumping might use another, sensitive or specific to the demands of the activity and mindful of the distorting effects the technology may introduce. Moreover, as we noted above, one cannot ignore the genuine conceptual concerns that his motion ought to be classified as 'running' or some related form of movement such as 'high-velocity bounding'.

Finally, if the guidelines on technology are excessively restrictive this may stifle future progress in therapeutic technology, which may be widely regarded as undesirable. Nevertheless, it is certainly incumbent upon the IPC and other disability sports regulatory bodies to develop transparent policies that assure a *reasonably* even playing field for the different resources for athletes representing all countries around the world.

Perspective

The evolution of assistive technology to enhance performance in sport, or just to conduct activities of daily living, was long overdue for persons with disabilities. Certain increases in mechanical performance of the assistive device are to be welcomed – especially if they reduce or remove undesirable performance inhibitors (such as may harm the athlete) and following evidence-based data (on the, albeit limited, applied research with Paralympic cohorts). The challenge for the future sports medicine and science research is to effectively 'match' the technology with the athlete and to ensure that it does so in a manner that preserves the integrity of sports contests and does so in a way that is accessible to all athletes at that level of competition in order to avoid Formula 1 style competition between engineers and technologists that are accessible to only wealthy individuals, teams, or nations. In some cases, arbitrations between advantages between individuals and teams on the grounds of unfairness will need to make appeal not merely to the evidential nature of the advantages gained but also to conceptual discussions about the nature of the contest that the sport instantiates. But the matter is of course not merely one of good science. On the contrary, good policy development here must take on a multidisciplinary character, of the kind that we have attempted here.

References

Brodtkorb, T., M. Henriksson, K. Johannesen-Munk, and F. Thidell. 2008. Cost-effectiveness of c-leg compared with non-microprocessor-controlled knees: A modeling approach. *Archives of Physical Medicine and Rehabilitation* 89: 24–30.

Brüggemann, G.-P., A. Arampatzis, F. Emrich, and W. Potthast. 2008. Biomechanics of double transtibial amputee sprinting using dedicated sprinting protheses. *Sports Technology* 1, no. 4–5: 220–7.

Burkett, B., W. Potthast, and M. Mcnamee. 2008. Technical boosting: The Oscar Pistorius case. In *International convention on science, education and medicine in sport*, 73–4. Guangzhou, China: People's Sports Publishing House.

Camporesi, S. 2008. Oscar Pistorius, enhancement and post-humans. *British Medical Journal* 34, no. 9: 639.

DePauw, K.P. 1988. Sport for individuals with disabilities: Reseach opportunities. *Adapted Physical Activity Quarterly* 5: 80–9.

Edwards, S.D. 2008. Should Oscar Pistorius be excluded from the 2008 olympic games? *Sport, Ethics and Philosophy* 2, no. 2: 112–25.

Foucault, M. 1998. *Technologies of the self*. Amherst: University of Massachusetts Press.

Friedman, J.L., and G.C. Norman. 2009. The paralympics: Yet another missed opportunity for social integration. *Boston University International Law Journal* 27: 345–66.

Fuss, F.K. 2008. Closing the gap through technology. *Sport Technology* 1, no. 4–5: 169–71.

Gard, M., and H. Fitzgerald. 2008. Tackling murderball: Masculinity, disability and the big screen. *Sport, Ethics and Philosophy* 2, no. 2: 126–41.

Habermas, J. 2003. *Faith and knowledge. The future of human nature*. Cambridge: Polity Press.

Haisma, J., L. Van Der Woude, H. Stam, M. Bergen, T. Sluis, and J. Bussmann. 2006. Physical capacity in wheelchair-dependent persons with a spinal cord injury: A critical review of the literature. *Spinal Cord* 44: 642–52.

Harris, J. 2010. The use, role and application of advanced technology in the lives of disabled people in the UK. *Disability & Society* 25, no. 4: 427–39.

Heidegger, M. 1977. *The question concerning technology and other essays*. Chicago: University of Chicago press.

International Association of Athletics Federations. 2009. IAAF competition rules 2009. http://www.iaaf.org/aboutiaaf/publications/ruels/index.html (accessed April 10, 2009).

Jones, C., and C. Wilson. 2009. Defining advantage and athletic performance: The case of Oscar Pistorius. *European Journal of Sport Science* 9, no. 2: 125–31.

Kretchmar, R.S. 1975. From test to contest: An analysis of two kinds of counterpoint in sport. *Journal of the Philosophy of Sport* 2: 23–30.

Lippi, G., and C. Mattiuzzi. 2008. Pistorius ineligible for the olympic games: The right decision. *British Medical Journal* 42, no. 3: 160–1.

Loland, S. 2002. *Fair play in sport. A moral norm system*. London: Taylor & Francis Group.

Magdalinski, T. 2008. *Sport, technology and the body: The nature of performance.* New York: Taylor & Francis.

Marcuse, H. 1964. *One-dimensional man*. London: Routledge.

Mcnamee, M.J. 2008. *Sports, virtues and vices*. London: Routledge.

Nolan, L., and A. Lees. 2000. The functional demands on the intact limb during walking for active trans-femoral and trans-tibial amputees. *Prosthetics and Orthotics International* 24, no. 2: 117–25.

Parrish, R., and S. Miettinen. 2008. *The sporting exception in European union law.* Cambridge: Cambridge University Press.

Pasquina, P.F., P.R. Bryant, M.E. Huang, T.L. Roberts, V.S. Nelson, and K.M. Flood. 2006. Advances in amputee care. *Archives of Physical Medicine and Rehabilitation* 87, no. 3S: 34–43.

Pickering-Francis, L. 2007. Competitive sports, disability, and problems of justice in sport. *Journal of the Philosophy of Sport* XXXII, no. 2: 127–32.

Stafilidis, S., and A. Arampatzis. 2007. Track compliance does not affect sprinting performance. *Journal of Sports Science* 25, no. 13: 1479–90.

Swartz, L., and B. Watermeyer. 2008. Cyborg anxiety: Oscar Pistorius and the boundaries of what it means to be human. *Disability and Society* 23, no. 2: 187–90.

Van Den Bogert, A., and M. Ackermann. 2009. *Effect of a prosthetic limb on sprint running performance*. Cape Town: International Society of Biomechanics.

Van Hilvoorde, I., and L. Landeweerd. 2008. Disability or extraordinary talent – Francesco Lentini (three legs) versus Oscar Pistorius (no legs). *Sport, Ethics and Philosophy* 2, no. 2: 97–111.

Weyand, P.G., M.W. Bundle, C.P. Mcgowan, A. Grabowski, M.B. Brown, R. Kram, and H. Herr. 2009. The fastest runner on artificial legs: Different limbs, similar function? *Journal of Applied Physiology* 107, no. 3: 903–11.

Wolbring, J. 2010. Human enhancement through the ableism lens. *Dilemata: International Journal of Applied Ethics* 2, no. 3. http://www.dilemata.net/revista/index.php/dilemata/article/viewArticle/31/46.