PARALYMPIC SPORTS, THE NEXT FRONTIER FOR SPORTS SCIENCE

Justin W.L. Keogh

Sports Performance Research Institute New Zealand, School of Sport and Recreation, AUT University, Auckland, New Zealand

The Paralympic Games is the pinnacle of sport for many athletes with a disability. The purpose of this paper is to briefly provide some background on the Summer Paralympic Games and their eligibility and classification rules. Results from selected studies examining the biomechanics of locomotion (amputee running, swimming and wheelchair pushing) and projecting external objects (e.g. throwing and hitting) as well as the evolution of sports performance and training practices such as strength and conditioning will be described. Recommendations for how this evidence can be used to improve athletic performance in Paralympic sports and inform future research are also provided.

KEY WORDS: adapted physical activity, biomechanics, sport for the disabled.

INTRODUCTION: Sport has not been traditionally advocated or emphasized for people with disabilities. This began to change in the middle of the 20th century with organised sport for these individuals beginning in Stoke Mandeville, England in 1948 (Bailey, 2008). This lead to the development of various organisations including the International Stoke Mandeville Games Federation in 1959, International Organization of Sport for the Disabled in 1964 and the International Paralympic Committee in 1989 (Bailey, 2008). As a result, Paralympic Games are now held directly after the Olympics Games, with the Paralympics held at the same host city as the Olympics from 1988 (International Paralympic Committee, 2009). The growth of the Paralympics Games is demonstrated by the fact that in the 2008 Beijing Paralympics there were 3,951 athletes from 146 countries competing in 20 sports (International Paralympic Committee, 2009). With the growth of the Paralympic Games, so too has society's views on these athletes changed. Instead of being viewed as people "suffering" from a disability, they are now often seen as inspiring high performance athletes. Such changes in public perceptions may have also altered the research emphasis, whereby many more research studies are now being conducted with a sports performance rather than rehabilitative focus. The remainder of this paper will focus on Parlympic athlete eligibility and classification, the biomechanics of Paralympic locomotion and projecting external objects, evolution of Paralympic sports performance as well as contemprary training practices.

ATHLETE ELIGIBILITY AND CLASSIFICATION: A wide variety of athletes can compete in Paralympic Games. In the 2008 Beijing Paralympic Games, classifications groups included spinal injury, amputee, visually impaired, cerebral palsy and les autres (International Paralympic Committee, 2009). As a result of the within- and between class heterogeneity of athletes, ongoing debate exists on how they should best be classified so to ensure fair competition (Jones and Wilson, 2009; Burkett, 2010; Tweedy and Vanlandewijck, in press).

LOCOMOTION: Paralympic athletes compete in a variety of sports where they need to move quickly when running, swimming, cycling (leg- or arm-propelled) or pushing a wheelchair. The following section will examine the findings of some selected studies that examined the biomechanics of amputee running, jumping, swimming and wheelchair propulsion.

Running and Jumping: The biomechanics of amputee running have recently been debated with allegations that individuals like the double trans-tibial amputee sprinter Oscar Pistorius who was attempting to qualify for the Beijing Olympic as well as Paralympic Games in 2008 was at an advantage over his intact-leg rivals due to his prosthetic limbs (Nolan, 2008; Burkett, 2010). As a result, Weyand et al. (2009) compared the biomechanical and physiological demands of Oscar Pistorius to elite intact-limb male 400 m sprinters. It was found that Oscar Pistorius had a similar or slightly lower metabolic cost during sub-maximal running, similar sprinting endurance but considerably different running mechanics than the intact-limb sprinters. Such results appear similar to the conclusions of Nolan (2008) in which after reviewing the literature, it was found that while there are considerable differences in the way that amputee and intact-limb sprinters actually sprint, there is little evidence to support the view that amputee runners are at any form of advantage. Several studies have also examined amputee jumping. During a study of the biomechanics of amputee long jump, Nolan and Lees (2007) observed many significant kinematic differences (e.g. hip and knee angle, height of centre of mass, stride length etc) at touchdown and takeoff of the last three strides prior to jumping for trans-femoral and trans-tibial long jumpers, with these values often different to that of intact-limb jumpers of similar standard.

Swimming: Several studies have been conducted involving Paralympic swimmers. Daly and colleagues (2001; 2003) found that Paralympic swimmers exhibit very similar race patterns to Olympic 100 m swimmers and that clean swimming, turning and finishing speed were highly correlated with race results, although the key phase was the second half of each 50 m lap. Daly et al. (2003) also observed that between-swimmer differences in 100 m speed were more related to stroke length than stroke rate, whereas within-swimmer changes in race speed were more related to changes in stroke rate. These results were extended by Osborough et al. (2009) who investigated how selected anthropometric characteristics were associated with the stroke length, stroke rate and swimming speed of 13 unilateral arm amputee swimmers. Similar to previous studies, it was found that within-swimmer changes in maximal speed were more associated with stoke rate than length. While no significant anthropometric correlates were found for stroke length, stroke rate at maximal speed was found to be significantly correlated to biacromial breadth ($r = 0.86$), shoulder girth ($r = 0.64$) and upper arm length ($r = 0.58$) (Osborough *et al.*, 2009).

Wheelchair: Wheelchairs are used for Paralympic athletic race events e.g. 100 m up to marathon and team sports such as wheelchair basketball, rugby and tennis. Some excellent, although slightly dated reviews of wheelchair locomotion are available (e.g. van der Woude *et al.*, 2001; Vanlandewijck *et al.*, 2001). One of the key findings of these reviews was that as the velocity of wheelchair locomotion increases, the propulsive style changes from circular to pumping, push time is significantly reduced, while the recovery time and push angle are relatively unchanged. These results have implications to training programs for these athletes as well as to the applicability of general research in this area to high performance sport.

Wheelchair sporting performance is directly influenced by the combination of three factors, the athlete, wheelchair and the wheelchair-athlete interface (Vanlandewijck *et al.*, 2001). These three factors in turn can directly influence the kinematic, kinetic and electromyographic characteristics of wheelchair propulsion, the degree of friction and air resistance encountered and the ability of the athlete to perform sport-specific activities e.g. catching, passing and hitting. As a result, wheelchair design continues to evolve, with a variety of specific chairs used across and even within Paralympic sports (Burkett, 2010). These specific chairs are required as unlike wheelchair race events, wheelchair team sports are characterized by frequent acceleration, deceleration and change of direction as well as requiring the athlete to hold a racquet and/or catch, pass or hit balls (Goosey-Tolfrey and Moss, 2005; Reid *et al.*, 2007). Unfortunately, little research has been conducted on the biomechanics of wheelchair team sports. Goosey-Tolfrey and Moss (2005) examined the effect of holding a tennis racquet on 20 m wheelchair sprint performance from a stationary position. The tennis players were significantly slower when holding their tennis racquet, with this effect most noticeable over the first three strokes (Goosey-Tolfrey and Moss, 2005). Such results may have implications for the design of on-court conditioning sessions for these athletes as well as for the tactics used during competition i.e. how to hold the racquet during the first few strokes when attempting to reach a ball hit by their opponent.

PROJECTING EXTERNAL OBJECTS: Even though many Paralympic sports involve projecting external objects e.g. throws and/or hits in athletics and team sports such as

wheelchair basketball, rugby and tennis, there appears to be much less research in this area than that for locomotion. Chow et al. (2000) examined the 3-D kinematics of 17 wheelchair shot putters and found that the average speed and angles of release of the shot were smaller than those of Olympic throwers. Significant correlations were observed between the height of release, angular speed of upper arm at release, shoulder girdle range of motion during delivery and average angular speeds of the trunk, shoulder girdle and upper arm during delivery to the classification and distance thrown (r = 0.52-0.79). Relatively similar results have also been observed for wheelchair javelin performance by Chow et al. (2003), suggesting that release parameters and the ability of selected upper body segments to obtain high angular speeds are critical for success in wheelchair shot put and javelin.
When performing flat and kick serves, Paralympic wheelchair tennis players produced significantly less racquet velocity and utilized somewhat different shoulder and trunk ranges of motion than their able-bodied peers (Reid *et al.*, 2007). However, as the Paralympic and able-bodied groups experienced relatively similar shoulder joint kinetics, both groups of tennis players may be at similar risks of shoulder injury when serving (Reid *et al.*, 2007). When comparing novice and elite wheelchair tennis players preparing to return serve from either a video or real opponent, Reina et al. (2007) found many significant differences. For example, during the ball toss the elite players focused more on the free arm and head/shoulders of the server. The elite players also had quicker reaction and movement times when facing serves from the real, but not video opponent. These results suggest that elite players are able to generate faster reaction and movement times, and ultimately likely improve their return of serve by utilizing some visual cues from their opponent.

EVOLUTION OF SPORTS PERFORMANCE: As the opportunities for people with disabilities to compete in sport at an elite level continues to increase, so too does their level of performance, with a total of 279 world records set at the 2008 Beijing Paralympics Games (International Paralympic Committee, 2009). However, only one scientific study has investigated the progression and variability of Paralympic sports performance. Using a sample of 120 male and 122 female Paralympic swimmers, Fulton et al. (2009) calculated the annual progression and variability in 100 m freestyle performances over a three year period. As between-competition variability and annual progression in performance were ~1.3% and ~0.5% respectively, Fulton et al. (2009) stated that Paralympic 100 m swimmers would need to improve by at least 1-2% annually to increase their medal chances.

TRAINING PRACTICES: Little research has examined training practices or the effects of strength and conditioning on Paralympic sport performance. Fulton et al. (2010) quantified the training of 16 Paralympic swimmers in the final 16 weeks of training prior to a World Championships. While these swimmers performed less weekly training volume than that of Olympic swimmers, they followed a similar periodized plan with respect to changes in volume and intensity. Fulton et al. (2010) however speculated that the Paralympic swimmers could have benefited from a more substantial taper prior to competition. Turbanski and Schmidtbleicher (2010) compared the effect of eight weeks of moderate load bench press training on the upper body performance of wheelchair athletes and college students. While both groups significantly improved bench press peak force, 1RM strength and maximum rate of force development, there were some trends ($p < 0.10$) for these effects to be greater in the wheelchair athletes and for the wheelchair athletes to improve 10 m sprinting speed.

CONCLUSION: The number of relevant articles found when completing this mini-review suggests that the majority of the research into the biomechanics and physiology of adapted physical activity has concentrated on non-athletic individuals performing activities of daily living rather than Paralympic athletes performing their sports-specific skills. Results of the limited sport performance studies suggest that while there are many similarities in the biomechanics and physiology of Paralympic and Olympic athletes, there are also many significant differences. Coaches and sport scientists who work with Paralympic athletes will therefore need to be aware of these similarities and differences if they are to contribute to the continual development of their athletes and to the overall evolution of Paralympic sports performance. Finally, I hope that this presentation has highlighted the opportunities for sport scientists to work with Paralympic athletes in either a sport science support or research role.

REFERENCES:

Bailey, S. (2008). *Athlete first: A history of the Paralympic movement*. Chichester, UK: John Wiley and Sons.
Burkett, B. (2010). Technology in Paralympic sport: performance enhancement or essential for performance? *British Journal of Sports Medicine,* 44, 215-220.
Chow, J.W. Chae, W.S. & Crawford, M.J. (2000). Kinematic analysis of shot-putting performed by wheelchair athletes of different medical classes. *Journal of Sport Sciences,* 18, 321-330.
Chow, J.W. Kuenster, A.F. & Lim, Y.-t. (2003). Kinematic analysis of javelin throw performed by wheelchair athletes of different functional classes. *Journal of Sports Science and Medicine,* 2, 36-46.
Daly, D. Malone, L. Smith, D. Steadward, R. & Vanlandewijk, Y. (2001). The contribution of starting, turning and finishing to total race performance in male Paralympic swimmers. *Adapted Physical Activity Quarterly,* 18, 316-333.
Daly, D. Djobova, S. Malone, L. Steadward, R. & Vanlandewijck, Y. (2003). Swimming speed patterns and stroking variables in the Paralympic 100-m freestyle. *Adapted Physical Activity Quarterly,* 20, 260-278.
Fulton, S.K. Pyne, D. Hopkins, W. & Burkett, B. (2009). Variability and progression in competitive performance of Paralympic swimmers. *J Sports Sci,* 27, 535-539.
Fulton, S.K. Pyne, D.B. Hopkins, W.G. & Burkett, B. (2010). Training characteristics of Paralympic swimmers. *Journal of Strength and Conditioning Research,* 24, 471-478.
Goosey-Tolfrey, V. & Moss, A. (2005). Wheelchair velocity of tennis players during propulsion with and without the use of racquets. *Adapted Physical Activity Quarterly,* 22, 291.
International Paralympic Committee. (2009). *Paralympic Games*. Retrieved 2nd March, 2010, from http://www.paralympic.org/Paralympic_Games/.
Jones, C. & Wilson, C. (2009). Defining advantage and athletic performance: The case of Oscar Pistorius. *European Journal of Sport Science,* 9, 125-131.
Nolan, L. (2008). Carbon fibre prostheses and running in amputees: a review. *Foot and Ankle Surgery,* 14, 125-129.
Nolan, L. & Lees, A. (2007). The influence of lower limb amputation level on the approach in the amputee long jump. *Journal of Sports Sciences,* 25, 393-401.
Osborough, C.D. Payton, C.J. & Daly, D.J. (2009). Relationships between the front crawl stroke parameters of competitive unilateral arm amputee swimmers, with selected anthropometric characteristics. *Journal of Applied Biomechanics,* 25, 304-312.
Reid, M. Elliott, B. & Alderson, J. (2007). Shoulder joint kinetics of the elite wheelchair tennis serve. *British Journal of Sports Medicine,* 41, 739-744.
Reina, R.I. Moreno, F.J. & Sanz, D. (2007). Visual behavior and motor responses of novice and experienced wheelchair tennis players relative to the service return. *Adapted Physical Activity Quarterly,* 24, 254-271.
Turbanski, S. & Schmidtbleicher, D. (2010). Effects of heavy resistance training on strength and power in upper extremities in wheelchair athletes *Journal of Strength and Conditioning Research,* 24, 8-16.
Tweedy, S.M. & Vanlandewijck, Y.C. (in press). International Paralympic Committee Position Stand - background and scientific rationale for classification in Paralympic sport. *British Journal of Sports Medicine.*
van der Woude, L.H.V. Veeger, H.E.J. Dallmeijer, A.J. Janssen, T.W.J. & Rozendaal, L.A. (2001). Biomechanics and physiology in active manual wheelchair propulsion. *Medical Engineering & Physics,* 23, 713-733.
Vanlandewijck, Y. Theisen, D. & Daly, D. (2001). Wheelchair propulsion biomechanics. *Sports Medicine,* 31, 339-367.
Weyand, P.G. Bundle, M.W. McGowan, C.P. Grabowski, A. Brown, M.B. Kram, R. & Herr, H. (2009). The fastest runner on artificial legs: different limbs, similar function? *Journal of Applied Physiology,* 107, 903-911.

Acknowledgement
I would like to thank the staff of Paralympics New Zealand and particularly their Coach Performance Manager, Mr John Bowden for their assistance in providing relevant material on the history and classification of Paralympics Games and feedback on an earlier draft of this paper.