Role of technology in athlete assessment

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Introduction

Many factors play a role in talent development. Factors related to both the athlete (i.e., rate of learning, training and maturation of anthropometric, physiological, technical, tactical and psychological skills), the environment (i.e., opportunities created by parents, trainers, coaches, and the competition structure), along with a component of chance (Elferink-Gemser & Visscher, 2012) – see Figure 11.1.

Progression in Para sport will also be dependent on the task characteristics associated with each sport. In Para Athletics, success in the sprint and field events will largely be determined by physical and technical progress. Other sports, like Wheelchair Fencing, will be strongly underpinned by technical skills. However, in sports such as the wheelchair court sports a large emphasis is placed on tactical awareness which is likely to be the biggest barrier to fast-tracking talented individuals into high-performing athletes. So, talent development is an interplay between the task characteristics, environment and performance characteristics (Figure 11.1).

In this chapter, the focus will be on the role of technology in athlete assessment to support talent development. Therefore, examples of technology for testing and monitoring performance characteristics such as anthropometric, physiological, technical, and tactical skills applicable to adapted sports will be described.
Technology for testing and monitoring of anthropometric characteristics

Anthropometric data are often used for talent identification. Factors such as body mass, height, reaching height, and sitting height are all often thought to be related to performance outcomes in specific contexts. The ability to reach can be dependent upon arm length but also on trunk stability, which is related to the disability of the athlete. Reaching can be measured by, for example, pushing away a tube as far as possible (Kouwijzer et al., 2020) which can be combined with inertial measurement units (IMUs) to measure trunk stability. Sitting height can also be a performance characteristic in some sports; for example, taller players are often thought to have an advantage in Wheelchair Basketball because their ability to reach higher into the air yields a better chance of shooting over an opponent, rebounding and blocking shorter players’ shots.

Body composition can also be more or less important in certain sports and is related to health. For example, in most rolling sports it is favourable to have a low fat mass since it leads to a lower rolling resistance and, therefore, better performance (van der Woude et al., 2001). However, a fat mass that is too low can have a negative effect on health so the body composition should be monitored carefully.

Endurance sport athletes show the lowest body mass from all sports; when comparing different wheelchair sports, the lowest fat mass was found in Para Cycling athletes (12.5 ± 6.5 kg) whereas curling game players showed the highest total fat mass (25.3 ± 4.9 kg) and basketball players showed the highest fat-free mass (Flueck, 2020). It seems worthwhile to track body composition in Para sport athletes to optimize the energy needs...
regarding to the training schedule as well as to optimize performance in weight-dependent disciplines (Flueck, 2020).

There are several methods to measure body composition (van der Scheer et al., 2021), which differ in feasibility, validity, reliability, and costs. The preferred method for measuring body composition is dual X-ray absorptiometry (DXA), which distinguishes between fat, lean tissue and bone mineral content and calculates those values for different body segments (Mazess et al., 1990; Nana et al., 2015). Since measuring the body composition with DXA is expensive, more feasible and cheaper methods (e.g., bioelectrical impedance analysis (BIA) and measurements of skinfolds) may be preferable. BIA is a non-invasive test in which two electrodes are placed on the athlete’s right hand and foot, if applicable, and a weak electric current is sent through the body. However, existing BIA as well as skinfold equations should always be used with caution in Para sport athletes, especially in athletes with substantial body asymmetry (Goosey-Tolfrey et al., 2016), such as those with limb loss, or for athletes with substantial muscle atrophy (Moore et al., 2015).

Another important aspect is monitoring the dietary intake to see whether the athletes’ intake balances their needs regarding calories and nutrients. Although various methods are available for gathering dietary data, those based on innovative technologies are particularly promising. With combined cost-effectiveness and ease of use, technologies like mobile phone applications can now optimize tracking of eating occasions and dietary behaviours (Simpson et al., 2017). However, it should be kept in mind that the estimation of energy needs is often based on the general population and is not always applicable to athletes with a disability. People with a spinal cord injury, for example, can have a 25% lower resting energy expenditure than the general population (Buchholz & Pencharz, 2004). Energy expenditure during exercise is also typically reduced in athletes with spinal cord injury between 25–75%, with the greatest energy expenditure reduction in athletes with tetraplegia or those participating in static wheelchair sports (Goosey-Tolfrey et al., 2014). Furthermore, the energy needs and expenditures of individuals with a central neurologic injury, such as cerebral palsy, vary greatly because of the wide range of associated functional impairment related to activities. Inefficiencies in ambulation and the presence of athetosis, spasticity, or ataxia, may all increase energy requirements, while decreased oral motor function may reduce oral intake (Crosland & Boyd, 2014). Consequently, body composition and energy balance (i.e., energy expenditure and intake) should be carefully monitored and individualised for all Para sport athletes during talent development.
Technology for testing and monitoring of physiological characteristics

When training for matches and races, normally the first goal is to become as fit as possible. This fitness is often expressed as the anaerobic and aerobic capacity. The anaerobic energy system is important for short-term performance, up to 1–2 minutes, and is most often estimated by the power output generated during a sprint or Wingate test (De Groot et al., 2012). The aerobic energy system reflects the ability to perform dynamic, moderate-to-vigorous intensity exercise with the largest possible muscle mass for prolonged periods of time. Peak oxygen uptake (VO$_2$ peak) and peak aerobic power output have been identified as important descriptors of the aerobic energy system and can be assessed with a graded exercise test until exhaustion (Baumgart et al., 2020; De Groot et al., 2012).

Both anaerobic and aerobic capacity relate to the match and race performance. For example, in an endurance sport like Handcycling (Nevin & Smith, 2020) and Para Triathlon (Stephenson et al., 2020), it was found that anaerobic and aerobic power are highly correlated with race time. Therefore, it is important to measure and monitor the anaerobic and aerobic capacity for designing and evaluating athletes’ strength and conditioning programs.

Research under laboratory and field conditions is complementary; the strength of one approach is the weakness of the other (Thompson & Vanlandewijck, 2020). For example, during field-based testing, the athlete can be tested in conditions closer to their performance environment, which results in a higher external validity, yet the changing environmental conditions make standardisation difficult. Control and reliability are both key advantages of laboratory-based testing. With new technologies, Para sport athletes can be tested in a standardized and sport-specific way in this environment. Graded exercise testing on a treadmill (running, wheelchair propulsion), bike ergometer (cycling) or armcrank ergometer (Handcycling) (Figure 11.2, left picture) are now more common ways of testing in Para sport populations. However, Paralympic athletes in sports where propulsion is achieved by using their arms were quite often tested on an armcrank ergometer while a more sport-specific way of testing would be more favorable. For example, Para Ice Hockey players can be tested while sitting in an ice sledge hockey seat during upper-body poling on a Concept2 ski ergometer (Baumgart et al., 2018).

Wheelchair athletes have been tested on treadmills as well as on wheelchair ergometers. The disadvantages of wheelchair ergometers were that they were not always commercially available and often had a fixed, but adjustable, chair (de Klerk et al., 2020). As a result, it is preferred to test athletes using their own equipment to see their real potential within the limits of their disability. With the commercially available Lode Esseda wheelchair
ergometer (Figure 11.2, right picture), it is possible to test wheelchair athletes in their own chair with a variety of test options such as isometric strength, isokinetic strength and (an)aerobic capacity (de Klerk et al., 2020). Sport-specific testing is important to assess the actual physical fitness and/or physiological attributes to design specifically tailored training protocols and periodization models and to increase the likelihood of success in competition. With sport-specific testing, strengths and weaknesses can be identified and this information can help athletes and coaches to adjust their training programmes.

Technology for testing and monitoring of technical characteristics

The technical skills needed for the different Paralympic sports are clearly important. The eventual performance depends on all components of the athlete-assistive device combination, like the use of a lower-limb prosthesis or a wheelchair. This can be subdivided in three major parts (Figure 11.3).
First, the athlete will determine the effectiveness of any assistive device, where the appropriate motor skills and physical capacity will determine whether the potential of the device can be used. Second, the assistive device also has its own characteristics like size, mass, stiffness and rolling friction, which need to change in line with the athlete’s development. Finally, the connection between the two (i.e., the interface) is defined as how athlete and device are connected and work together. This not only means the literal connection, like a prosthesis socket or wheelchair seat, but also the way they interact in the sense of translating energy from the athlete, via the device, onto the environment, such as the type of knee joint used, or the connection of the hand to the handrim.

Since performance depends on this athlete-assistive device combination, understanding the biomechanics of this combination is key to optimize performance. Therefore, it is not only important to train the physiological capacity of the athlete but also the skill to transfer the power from the hand to the wheelchair rim. Furthermore, an individually optimally tuned interface between the athlete and wheelchair is essential for a good performance. Take, for instance, the skill and interface necessary for coupling the hand with racket to the handrim during Wheelchair Tennis (de Groot et al., 2017). Understanding the interplay between the athlete, interface and wheelchair is very hard and it is not always easy to predict the eventual performance, especially given the variability of human motor control and individual differences in motor skill acquisition. Fortunately, the performance outcomes can be measured and evaluated to optimize an athlete’s performance. Below some of the laboratory tools for such measurements are discussed.

Next to overground testing, a treadmill can provide an effective testing environment, where speed and power output can be standardized and controlled. A single axis force transducer can be used to measure the power output through a drag test (Figure 11.4, right). Treadmill inclination or a pulley system can consequently be used to impose the desired power output (Figure 11.4, left). Although treadmills have some advantages, like the need to control left-right power output to go in a straight line, they are more suited for steady-state velocities, rather than acceleration or measurements at very high speeds.

An instrumented roller ergometer (Figure 11.2, right) can be an excellent alternative for sprint testing. Moreover, since the rollers are instrumented, high-frequency continuous measurements of power output can be available in contrast to measurements on a treadmill. These measures can be used to understand wheelchair propulsion biomechanics (Figure 11.5), for example, to evaluate upper-limb asymmetries in wheelchair athletes (Goosey-Tolfrey et al., 2018).

The development of wheelchair ergometers have a long history (de Klerk et al., 2020). Such devices have integrated test protocols to measure isometric
FIGURE 11.4  Experimental setup. Left: To impose the desired power output a pulley-system is attached to the wheelchair on the treadmill. Right: A drag test is performed to determine power output of the user-wheelchair combination.

FIGURE 11.5  Illustration of the power output signal from the wheelchair ergometer and definition of some wheelchair propulsion outcomes: push time (from push start to push end), cycle time (from push start to push start), and power loss before (PnegS) and after (PnegE) the push time.
force and (an)aerobic exercise capacity and thus can be applied for profiling and systematically monitoring the effect of training or changes to the assistive device (Janssen et al., 2021). Furthermore, the wheelchair ergometer can be used during training and direct visual feedback of propulsion technique variables, such as peak force and push time, can be provided to the athlete and coach on a monitor during propulsion to improve specific aspects of wheelchair propulsion (Richter et al., 2011).

In addition to the wheelchair ergometer a number of common measurement tools can be added, such as three-dimensional position registration and electromyography (EMG) to measure muscle activity (Figure 11.6). These more advanced testing setups can be used to answer biomechanical questions about the performance of an athlete (Figure 11.7). Since the upper-limb is a very mobile joint, actually understanding the complex dynamics and kinematics is difficult. The rotator-cuff is actively needed to stabilize the shoulder joint, but also contributes to the force application onto the handrim (Vegter et al., 2015). Moreover, although the task seems fairly constrained, there are still a lot of different degrees of freedom (Mason et al., 2018). The study of Mason et al. (Mason et al., 2018) nicely illustrates the use of these techniques by applying them to understand the role of the scapula and asymmetries in posture and chair positioning in relation to pain and performance in wheelchair athletes.

Developments in technology over recent years have made field-based performance monitoring increasingly accessible to Para sport athletes. IMUs, which typically include accelerometers, gyroscopes and magnetometers, can be
FIGURE 11.7  Measuring kinetics and kinematics and visualizing the outcomes (photo credit: Riemer Vegter)
attached around the wheel axis and frame of sports wheelchairs (Figure 11.8). IMUs can provide real-time feedback about linear and rotational acceleration and velocity metrics (van der Slikke et al., 2020). If used longitudinally during standardised field tests, these devices can serve to map out an individuals’ progress over time and can help identify the strengths and weaknesses for specific athletes such as left-right symmetry or acceleration from standstill. It provides coaches and practitioners with evidence-based information about the areas that need improving and they can adjust their programmes and practice accordingly to improve these areas. This individualised approach is an important and necessary step when developing talented athletes into high-performance athletes and can serve to expedite this process.

A benefit of IMUs is that they can also be used in non-standardised conditions (i.e., during match-play scenarios) to monitor the performance and progression of athletes during competitive situations. In this type of environment, miniaturised data loggers (MDL) and radio-frequency based indoor tracking systems (ITS) are also viable options for performance monitoring. MDL are wheel-mounted devices that work via reed switch technology and every time a wheel rotates, a magnetic pendulum activates a reed switch to produce a time stamp (Tolerico et al., 2007). With known wheel dimensions, speed and distance metrics can be calculated alongside the number of starts and stops performed. An ITS operates in a very similar way to Global Positioning Systems (GPS), whereby sensors are positioned...

FIGURE 11.8 Inertial Measurement Units (IMUs) attached around the wheel axles and frame (photo credit: Sonja de Groot)
around the perimeter of an indoor court. After a series of calibration procedures, these sensors communicate wirelessly with small, lightweight tags secured to an athletes’ chair. This provides real-time location data, which can be used to calculate similar metrics to the MDL. The added value of the ITS is that because location data is provided, additional context can be acquired about where on court certain activities are being performed (Figure 11.9). This adds a layer of tactical detail to performance monitoring that will be discussed in the next section.

Scientific research using these technologies during match-play have identified the key mobility characteristics of higher ranked teams/players and how their activity profiles may differ compared to lower ranked teams/players in Wheelchair Basketball, rugby and tennis. For example, the linear and rotational performance of international Wheelchair Basketball players compared to national level players has been captured using IMUs (van der Slikke et al., 2016). These metrics, which were all found to be greater in international players compared to national level athletes, can be used to help benchmark athlete development. Similarly the activity profiles elicited by international Wheelchair Rugby players (Rhodes et al., 2015) and Wheelchair Tennis players (Mason et al., 2020; Sindall et al., 2013) have also been documented using MDL and ITS. This information is incredibly valuable for the development of athletes since it paints a clearer picture of what is required to be a high-performance athlete and if the technology can be used longitudinally, progression can be monitored along the performance pathway. However, accuracy and reliability (MDL) and cost/expertise (ITS) required must always be considered when determining the appropriate technology for the job. IMUs are a cost effective, easy to use, accurate and reliable (van der Slikke et al., 2015) alternative to measure wheelchair performance. Recently, the first attempts have been made to also estimate the power output from IMUs attached to the axle and the wheels (Rietveld et al., 2021). Power output is an objective measure of training load. Nowadays, every elite (hand)cyclist uses a commercially available power meter (Abel et al., 2010; de Groot et al., 2018). In contrast, unfortunately there is not yet a (commercially available) power meter for wheelchair athletes to monitor the external training load next to internal training load measures such as heart rate and rating of perceived exertion.

**Tactical**

Activity profiles of wheelchair court sport athletes, discussed in the previous section, have also been explored in relation to the outcome of the performance (i.e., winners versus losers) or the ranking/status (high ranked versus low ranked) (Mason et al., 2020; Rhodes et al., 2015; Sindall et al., 2013). These studies have demonstrated that very few differences in activity
FIGURE 11.9  Examples of how location data can be used to calculate metrics and to give additional context on where on court certain activities are being performed.
profiles existed between high and low-ranked teams in Wheelchair Rugby (Rhodes et al., 2015). Similarly, observations were made in Wheelchair Tennis, where it was revealed that players who lost the match actually performed more high-speed activity than players who won (Mason et al., 2020). Therefore, although the physical capacity of higher ranked athletes may be greater in some contexts, they do not appear reliant on these factors to win games and be successful. This suggests that there is a dynamic interaction of physical, technical and tactical elements that support optimal development and performance.

Subsequently, time motion analysis of the ball handling skills and tactics employed during match-play may offer also an important insight into what determines successful performance in such sports and how these can be monitored to support the development of individuals. This was reinforced in Wheelchair Tennis whereby winning players were characterised by a higher number of winners and fewer errors during a range of technical strokes, compared to any physical measures of performance (Mason et al., 2020). Performance analysis has been used more extensively in Wheelchair Basketball whereby matches have been filmed and the activities performed have been coded using specialised software, such as SportsCode (Francis et al., 2019). These studies have identified specific line-ups that yield higher chances of success than others according to athletes’ classification (Francis et al., 2019; Gómez et al., 2015; Molik et al., 2009; Vanlandewijck et al., 2004). Specific tactical patterns of play that lead to a better chance of success have also been identified. In particular, zonal defensive strategies have been advocated to i) generate more pressure and force more turnovers from opposing teams, and ii) create patterns of play that result in more open shots which yield a greater chance of success (Francis et al., 2019).

Subsequently, access to video analysis feedback within the court sports, where tactical awareness is likely to be the biggest barrier to fast-tracking talented individuals into high-performing athletes could be imperative. Learning is likely to be accelerated from simply viewing their own performances back. However, with the feedback of detailed metrics documenting tactical aspects of the talents’ performance, it is highly likely to accelerate their learning. Given the improvements in analysis software over recent years, whereby the coding of activities is far easier and the feedback can be provided during games or immediately after.

**Practitioner commentary**

The use of technology, as rightly discussed by the authors, has a wide range of roles in supporting Para athlete development, from performance analysis to monitoring body composition. The ability to integrate technology within sport environments with minimal disruption to training is the greatest
challenge. As researchers and practitioners, we are improving, and this is resulting in greater adoption of technology to support athlete development across the whole pathway.

In practice, one of the more difficult aspects is providing effective feedback. Whether this is technical or tactical, simple improvements in technology (or access to technology and personnel) can change how (e.g., visual in addition to verbal) and when athletes receive feedback. The ability to capture video and replay during training (often in slow motion) allows detailed discussion between the athlete and their coach/support on both technical (e.g., propulsion technique in swimming) and tactical components (e.g., review of planned/structured plays in Wheelchair Rugby). This can be a relatively simple solution in cases where filming and replay is straightforward. However, many training environments, particularly in Para sport contexts, come with their own challenges: minimal support for technology set-up and operation, working with a group of athletes and providing group and individual feedback, or athletes training in remote locations. From my experiences, the more effort associated with using technology, the less likely it is to be implemented and used regularly. The next step for wider adoption of technology discussed by the authors (such as IMUs, MDLs, etc.) requires work to reduce the set-up, operation, and analysis requirements – which is already happening through continued development and research. Semi-permanent installations can help with this where possible, reducing the need for additional support in training sessions. In most cases, the feedback required is not complex – it is the ability to provide clear, key points efficiently and immediately (through available software or expertise if available) that can aid athlete development and support future planning.

Another area in Para sport contexts that has shown considerable progression in recent years is the individual customisation of equipment interfaces. As the authors discuss, interaction between the hand and push rim is critical in ensuring power is transferred to the wheels optimally in wheelchair sports. In Wheelchair Racing, gloves are now being developed from scans of athlete hands and preferred grip positions, with designs then 3D printed specifically for that individual. A similar process can be followed for individualised carbon moulded seats to improve performance, which are lighter, stronger, and more suited to the individual. As technology becomes more widely available, more equipment will continue to be customised for the individual, and for newer athletes earlier in the pathway. Interventions like this require adaptation periods, where the ability of technology to monitor performance and allow support like skill acquisition experts to provide feedback is again essential.

Sports, and particularly Para sport, should continue to adopt and adapt with technology and integrate it within their environments where suitable.
Achieving this will allow for improvements in feedback, athlete monitoring, and equipment development. Part of our role as practitioners and researchers is to develop methods to facilitate this and support the development of our coaches and athletes.

References


