Review Paper

Wheelchair tennis, from health to competitive analysis: A narrative review

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ABSTRACT

Objective: The purpose of this article is to analyse benefits of the playing wheelchair tennis in people with disabilities and to know some aspects that affect a player´s performance. Methods: Keyword search of Medline, SPORT Discus and Scholar Google databases was conducted to find relevant studies pertaining to: wheelchair tennis and adapted sports. The search was carried out from 1988 to February 2018. Also reference lists of articles obtained were manually searched for relevant literature. Narrative review methods were used to synthesise the data. Results: The psychology literature was limited, although wheelchair tennis seems to provide a reduction in depression and trait anxiety and an increase in vigour. Playing wheelchair tennis is sufficient to prevent the development of cardiovascular diseases, due the energy expenditure is comparable to the recommendations of the American College of Sports Medicine. Wheelchair mobility seems to be an important factor of success in WT, and the chair configuration affects the moving speed. Conclusions: Following the studies presented in this paper, we recommend that people with disabilities playing sport to improve their health condition. Also, coaches and fitness trainers can use the information provided within this study to adapt and improve the specific training programs for players.
Keywords: Adapted sport; Tennis; Benefits; Performance.

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INTRODUCTION

At the end of World War I, many people had survived with a disability, but the care they received was almost zero, so between 80% and 90% of people with a spinal injury died within a few weeks (Guttmann, 1976). In 1944 Dr Ludwing Guttmann applied sports activities as part of rehabilitation process for spinal cord injuries of World War II to raise life expectancy. Shortly thereafter, under the direction of Doctor Guttmann, the first Stoke Mandeville Games for Paraplegics were held (Sanz & Reina, 2012). And since 1960, disabled athletes have been taking part in the Olympics.

Below is a review of wheelchair tennis ranging from health to competitive perspectives.

WHEELCHAIR TENNIS AS A HEALTHY SPORT

Regular physical activity is associated with multiple positive outcomes among individuals with physical disabilities, improving quality of life (Crawford, Hollingsworth, Morgan, & Gray, 2008), and playing adapted sports is a proven effective activity for improving the health status and quality of life of people with physical impairments (Côté-Leclerc et al., 2017; Yazicioglu, Yavuz, Goktepe, & Tan, 2012). For that reason, fitness should be an integral part of the daily routine for individuals with a musculoskeletal or neurological disability. The effects of physical activity extend far beyond improved mobility and associated health benefits to include changes in an individual's quality life (Steadward, 1998).

Psychological benefits

Individuals with physical disabilities can experience considerable psychological and social hardship (Richardson, Papathomas, Smith, & Goosey-Tolfrey, 2015). Physical activities have been used as a means of improving the health status of people with disabilities (Crawford et al., 2008). Wheelchair tennis is one of the adapted sports that facilitates psychological improvement, including for athletes from developing countries (Richardson et al., 2015).

The psychological benefits that wheelchair tennis can provide include a reduction in depression and trait anxiety and an increase in vigour (Muraki, Tsunawake, Hiramatsu, & Yamasaki, 2000). Moreover, wheelchair tennis players are aware of the importance of taking part in sport from a health point of view, and that is one of the main reasons for them playing wheelchair tennis (Wu & Williams, 2001).

In many hospitals, people with spinal injuries undertake rehabilitation programmes and participate in different sports. This context is the most important aspect of introducing sport after an injury to individuals (Wu & Williams, 2001). After the programme, players should play wheelchair tennis more than three times a week, because the higher the frequency, the greater the benefits (Muraki et al., 2000).

Cardiovascular benefits

It has been scientifically established that wheelchair users are at greater risk of cardiovascular problems than able people (Cardinal, Kosma, & McCubbin, 2004). Research aimed at identifying effective measures to prevent disease is of central importance (Abel et al., 2003).

Wheelchair tennis is characterized by an intermittent activity profile with periods of explosive effort superimposed on a background of aerobic activity (Goosey-Tolfrey, Castle, Webborn, & Abel, 2006) showing a moderate to high level of cardiovascular and metabolic stress (Roy, Menear, Schmid, Hunter, & Malone, 2006).

Wheelchair tennis matches last between 50 and 80 minutes (Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2014) and players are active for a duration associated with positive health-enhancing effects (Sindall, Lenton, Tolfrey et al., 2013). Not only the match but also practice (training) conditions elicit a sufficiently high heart rate (HR) to be considered beneficial physical activity (Barfield, Malone, & Coleman, 2009). Moreover, the level of energy expenditure in a match is comparable to the recommendations of the ACSM for able-bodied persons, and therefore might be sufficient to prevent the development of cardiovascular diseases (Abel et al., 2008).

It is important to note that playing wheelchair tennis requires a significant technical level (mobility and hitting). The length of points appears to be shorter in amateur (Filipčič & Filipčič, 2009b) than among high-level players (Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015). Therefore, in order to increase mobility and the length of points, using a low-compression ball could be a good option for amateur WT players (Sindall et al., 2014).

WHEELCHAIR TENNIS AS A COMPETITIVE SPORT

Over the last two decades, there has been very rapid growth in the Paralympic movement, with an increasing number of countries and athletes participating in these games (Bernardi et al., 2010). Wheelchair sport is now an organized leisure time activity as well as a competitive sport and has gained popularity, especially in ball games such as wheelchair basketball, wheelchair rugby and wheelchair tennis (Abel et al., 2008). Wheelchair tennis (WT) is now firmly established as one of the public's favourite Paralympic sports (Diaper & Goosey-Tolfrey, 2009) and one of the top four Paralympic sports (Tennis Canada, 2008). The competitive wheelchair tennis level has risen in recent years. However, doping controls have shown a higher percentage of positive cases among wheelchair tennis players than conventional tennis players in recent years (Maquirriain, 2010).

WT was a Paralympic sport in Barcelona in 1992. Since then, WT has grown professionally on court and institutionally off court, having a presence in over 41 countries with approximately 160 international tournaments within the NEC circuit (Bullock & Sanz, 2010; ITF, 2018). WT matches are always played as best of three sets and the main difference regarding regulations in comparison to conventional tennis (CT) is that the ball can bounce twice before one must return it (ITF, 2018).

There are two categories, Open and Quad. In the Open category, men and women play in different draws and have a wide range of disabilities, including spinal cord injury, single amputees, double amputees and spina bifida. In the Quad category, men and woman play together and have a disability in their upper limbs as well; this was introduced to the tennis programme at the 2004 Paralympics (Goosey-Tolfrey et al., 2006).

The number of international wheelchair tennis players (male, female, quad and juniors) is close to 1,000 and the total prize money for the tour in 2018 was over 2.5 million dollars (ITF, 2018), so controlling player performance is important from a professional point of view. The introduction of sports science support for this sport had a profound and overall positive impact on the sport (Diaper & Goosey-Tolfrey, 2009). In that sense, we will deal about some aspects that affect a player´s performance.

Match analysis

Activity pattern

Wheelchair tennis is an intermittent sport. Aspects such as rest time between points (20 seconds) and changes of ends (90 seconds) are the same as in conventional tennis (ITF, 2018) and these determine the structure of the sport.

Activity patterns have been studied over the last 10 years and show the total time of a high-level singles match to be between 50 and 80 minutes (Croft, Dybrus, Lenton, & Goosey-Tolfrey, 2010; Roy et al., 2006; Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015; Sánchez-Pay, Torres-Luque, Fernandez-García, & Sanz-Rivas, 2013; Sindall, Lenton, Tolfrey, et al., 2013), the effective playing time to be around 15–20 % of the total playing time, which is equivalent to a ratio of working time to resting time of around 1:4 (Filipčič & Filipčič, 2009b; Roy et al., 2006; Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015), and the rally duration to be between 6 and 10 seconds, with three to four shots per rally (Bullock & Pluim, 2003; Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015; Veltmeijer, Pluim, Thijssen, Hopman, & Eijsvogels, 2014). These values seem to be lower at the recreational level in terms of total playing time, shots per rally and rally duration (Filipčič & Filipčič, 2009b). These values are used by coaches and fitness trainers to improve the specific training programmes through a number of exercises, repetitions, working times and resting times, etc.

Mobility

Wheelchair mobility is an important factor of success in WT (Bullock & Pluim, 2003). Optimizing mobility performance in wheelchair tennis is dependent on a combination of factors associated with the user, the wheelchair and the interfacing between both (Mason, Van Der Woude, & Goosey-Tolfrey, 2013). Movement enables the player to prepare him/herself adequately for a stroke and to execute the maximum number of strokes (Filipčič & Filipčič, 2009a).

The movement dynamics of wheelchair tennis are specifically related to propelling the wheelchair while holding a tennis racquet (Goosey-Tolfrey & Moss, 2005). The specific movements of the tennis wheelchair-user interface include starting, sprinting, braking and turning (Sanz, 2003). Movement during a competitive WC tennis match is intermittent, multidirectional and non-random, which challenges the participant to change direction many times (Roy et al., 2006), so the ability to accelerate quickly from a standstill is considered more important than sprinting (Vanlandewijck, Theisen, & Daly, 2001). WT players need to maintain the inertia of the chair for greater performance (Coutts, 1990), but the specific movement of the players includes turns (Sanz, 2003) and the changes in the inertia are more pronounced the faster they turn (Caspall, Seligsohn, Dao, & Sprigle, 2013). For that reason, the most effective propulsion strategy would result in obtaining maximum velocities in the least amount of pushes possible (Goosey-Tolfrey & Moss, 2005). Maximum velocities and peak velocities achieved during the first three pushes are restricted due to the presence of a racquet (Goosey-Tolfrey & Moss, 2005; Sánchez-Pay & Sanz-Rivas, 2019). Moreover, propelling the wheelchair while holding a racket has a negative influence on the propulsion technique and could lead to injuries of the upper extremity (De Groot, Bos, Koopman, Hoekstra, & Vegter, 2017). This could be due to the longer time needed to hold simultaneously with the hand the racket and the rim, which leads to higher power losses and subsequently higher power output generated during the shorter push phase (De Groot et al., 2017) – aspects that should be considered by coaches. Other types of rims (for example a square rim profile) have been tested and been shown to have a negative influence on maximum speed and acceleration (de Groot, Bos, Koopman, Hoekstra, & Vegter, 2018).

Global positioning satellite (GPS) systems enable the movement challenges associated with sports activity to be quantified (MacLeod, Morris, Nevill, & Sunderland, 2009). GPS systems track common movement

patterns, allowing coaches to optimize tactics and court movement strategies (Sindall, Lenton, Whytock et al., 2013). In the case of WT matches, current GPS systems of 1 Hz are not sufficient to record the amount of distance covered by a player, and his/her speed, during a match (Sindall, Lenton, Whytock, et al., 2013), so other systems have been used for this. Other devices and/or software have recorded that players move more than 3,000 metres, at an average speed of 1 m/s and maximum speeds of up to 3 m/s (Sindall, Lenton, Tolfrey, et al., 2013), with the top-level players moving further and faster than the lower-level ones (Filipčič & Filipčič, 2009a; Sindall, Lenton, Tolfrey, et al., 2013), showing relationships between trunk stability and wheelchair velocity characteristics (Goosey-Tolfrey & Moss, 2005).

Most of the movements of WT players are performed in the central area of the court, behind the baseline (Filipčič & Filipčič, 2009a). In addition, winning players have faster average speeds than losing players (Filipčič & Filipčič, 2009a), although there seem to be no differences in terms of distance and playing zone between winning and losing players (Filipčič & Filipčič, 2009a; Sindall, Lenton, Tolfrey, et al., 2013) or even between surfaces (hard and clay courts) (Ponzano & Gollin, 2017). It seems that a greater extent of movement means greater playing efficiency (Filipčič & Filipčič, 2009a). Nevertheless, differences need to be pointed out, such as methods of mobility, movements to the ball and the two bounces allowed, the basic stroke sequence, recovery approaches, generating torque, recovery and physical considerations (Filipčič & Filipčič, 2009a).

Performance indicators

As previously mentioned, rally duration ranges between 6 and 10 seconds, with three to four shots per rally (Bullock & Pluim, 2003; Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015; Veltmeijer et al., 2014). More than 40% of all points finish in one or two shots (Sánchez-Pay, Sanz-Rivas, & Torres-Luque, 2015), so serving/returning scenarios are vital in WT (Sánchez-Pay, Torres-Luque, & Sanz-Rivas, 2015) and seem to be extremely important in match performance.

The serve is a decisive stroke and does not favour the server (as is the case in conventional tennis) but rather the receiver. WT players have a lower height impact and less lower-body strength generation than standing players, so they have less power when hitting than standing players (Reid, Elliott, & Alderson, 2007). This results in a greater number of double faults, fewer aces and more winner return shots among WT players than standing players (Sánchez-Pay, Palao, Torres-Luque, & Sanz-Rivas, 2015; Sánchez-Pay, Torres-Luque, Cabello Manrique, Sanz-Rivas, & Palao, 2015). It is also important to note that in the Open and Quad divisions, the players experience a wide range of types of injury, all of which affect impact height and stroke power (Cavedon, Zancanaro, & Milanese, 2014).

Physiological demands

Previously wheelchair tennis was described as a healthy sport. Early studies on the physiological demands on wheelchair tennis players justified wheelchair tennis as a healthy adapted sport (Abel et al., 2008; Coutts, 1988; Roy et al., 2006). Measures of heart rate (HR) response can provide information on the overall intensity, physiological stress and metabolic cost of participation in sport (Roy et al., 2006). Playing wheelchair tennis presents an HR of between 120 and 140 beats per min (b.p.m.), with 65–75 % of maximum HR and a maximal oxygen uptake (VO2max) estimation of between 50 and 68 % (Barfield et al., 2009; Bernardi et al., 2010; Croft et al., 2010; Roy et al., 2006; Sánchez-Pay, Torres-Luque, & Sanz-Rivas, 2015; Sindall, Lenton, Tolfrey, et al., 2013). Recent studies have examined physiological demands in a wheelchair tennis match from a performance point of view. Sindall et al. (2013) showed that the intensity of a match (HR) was similar in relative terms when direct comparisons were made between a high-ranked player and a low-ranked player. All these studies took samples on a hard court. Only Sánchez-Pay et al.'s (2015) study measured

performance on a clay court, showing HRs of about 125 b.p.m, values similar to other studies (Barfield et al., 2009; Bernardi et al., 2010; Croft et al., 2010; Roy et al., 2006; Sindall, Lenton, Tolfrey, et al., 2013), although HR_{max} was slightly higher (76%).

Other variables such as blood lactate concentration (LA) and rates of perceived exertion (RPE) in game situations have been used to control the physiological demand of wheelchair tennis matches, showing about 2 mmol l^{-1} and 12–13 points on the RPE scale (Abel et al., 2008; Sánchez-Pay, Torres-Luque, & Sanz-Rivas, 2015; Veltmeijer et al., 2014).

The intermittent nature of the sport in a WT match means that the players have intermittent exercise bouts and a multitude of rest periods over a long duration (Sánchez-Pay et al., 2014), so wheelchair tennis training requires training across the exercise intensity spectrum (Croft et al., 2010).

Extreme environmental conditions

The wheelchair tennis tour includes more than 160 international tournaments across the five continents. An international tournament takes place over two to seven days and is often played in hot and humid climates with players regularly required to play more than one match in a day (singles and doubles) (Diaper & Goosey-Tolfrey, 2009). Temperatures are often above 30 degrees with more than 70% humidity (Girard, 2015). The last Paralympic Games were held in Rio de Janeiro in 2016 (Brazil), so players had to play in high levels of humidity and hot temperatures. Some wheelchair tennis players have a spinal cord injury and this affects core temperature, increasing body temperature in respect to able-bodied players in laboratory conditions (Price & Campbell, 2003). This translates to the tennis court, where wheelchair tennis players with a spinal cord injury have a slight increase in body temperature in respect to players without a spinal cord injury (Veltmeijer et al., 2014). A simple method such as hand cooling seems to be an effective way to reduce core temperature during recovery after prolonged exercise in the heat in wheelchair tennis players (Goosey-Tolfrey, Swainson, Boyd, Atkinson, & Tolfrey, 2008).

Kinematics and injuries

Many wheelchair tennis players are wheelchair users in their daily lives. The scapulohumeral joint is frequently used for repetitive movements (Bernard, Codine, & Minier, 2004), so shoulder pain is a common problem in manual wheelchair users (Fullerton, Borckardt, & Alfano, 2003). Nearly 80% of individuals with spinal cord injury have been reported to have shoulder pain (Fullerton et al., 2003), and the figure is higher in individuals with tetraplegia than in individuals with paraplegia (Curtis et al., 1999).

The shoulder is one of the most important joints for the wheelchair tennis player. Players use it to move and hit the ball. Stress in this joint is manifest. Moreover, the use of the chair and the stroke movement generate greater use of some muscle groups than others. There is an unusual imbalance potential in upper-limb function due to the nature of the sport (Moon, Park, Kim, & Jang, 2013) with bilateral asymmetries and differences to able-bodied participants with shoulder impingement (Warner et al., 2018), so it is common for WT players to present pathology in the rotator cuff and acromioclavicular in both dominant and non-dominant shoulders (Jeon et al., 2010).

WT players move the chair with both arms but hit the ball with one hand. It is obvious that there are more loads on one than another. This situation produces in the upper limb ipsilateral balance ratio (between shoulder and elbow) and low muscle strength balance ratio of the elbow joint in flexion and extension movements (Moon et al., 2013), showing differences between external and internal rotators on the non-dominant side for peak torque and mean power (Bernard et al., 2004). For this reason, Moon et al. (2013)

indicate that a flexor-strengthening programme should be introduced for the non-dominant shoulder joint, an extensor-strengthening programme for both elbows joint and a flexor-strengthening programme for the non-dominant elbow joint for male wheelchair tennis players.

Wheelchair tennis is a non-direct contact sport with the opponent in comparison to wheelchair rugby or wheelchair basketball. Nonetheless, WT, along with volleyball, was the non-direct contact sport with the most injuries at the Rio 2016 Summer Paralympic Games (Derman et al., 2017), although it seems to have had a lower overall incidence rate of injury compared with the London Games (Willick et al., 2013).

PRACTICAL APPLICATION AND CONCLUSIONS

Wheelchair tennis is a sport recommended for people with physical disabilities because it provides for players a set of benefits in terms of health conditions. It could be a competitive sport, including at high-performance level, but WT could also be practised as a recreational sport with all the benefits (social, physical, psychological) described before.

As regards high performance, for players who are involved in this field, nowadays WT requires attention to be given to the training systems because of the professionalism of this sport and the requirements (volume of training and competition intensity). Thus, we have to take care not only of the player but also the equipment, including the wheelchair, because the chair configuration affects the upper-body kinematics (Gorce & Louis, 2012), such as the moving speed (Kotajarvi et al., 2004). The wheelchair tennis player is constantly changing directions, so repeated sprint ability and changes of direction seem to be important in order to be competitive in wheelchair sports. With these specific movements, the centre of gravity of the subject varies constantly. The seating position player has a direct influence on the speed, as this directly affects the rolling resistance and stability (Bascou et al., 2012), so much so that stability in the chair is considered the most important factor of athletic performance by athletes in wheelchairs (Mason, Porcellato, Van Der Woude, & Goosey-Tolfrey, 2010), which is why it is recommended to include specific upper-body repeated power ability drills in the physical preparation of WT players (Schuster et al., 2018). All these aspects must be considered by coaches and physical trainers when performing exercises.

Moreover, this correct position in the chair could prevent potential injuries because the player will be more efficient in the chair, in terms of both mobility and impacts. Thus, following the studies presented in this paper, we recommend that people with disabilities practising sport should improve their health condition and, above all, practise tennis for the benefits implicit in this sport, notwithstanding the player's goal (i.e. recreational or competitive).

The intervention of the coach or physical trainer will be crucial in order to respect the evolution and prevent injuries during practice. However, we need additional research in order to increase knowledge in several areas, such as control and motor learning, biomechanics (a technique required to make the strokes), tactics (notational analysis), and psychological and sociological aspects. Further research will develop a better understanding of this important modality in wheelchair tennis (Villaplana & Fuentes, 2015).

AUTHOR CONTRIBUTIONS

ASP reviewed the literature and performed the structure of the manuscript. ASP and DSR wrote and supervised the work critically.

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The authors declare no conflicts of interest.

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