VALIDITY AND RELIABILITY OF AGILITY AND HITTING ACCURACY TESTS IN WHEELCHAIR TENNIS ATHLETES

by

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ABSTRACT

Movement in competitive wheelchair tennis is multidirectional and intermittent with a high number of directional changes. The physiological demands of wheelchair tennis are much less understood than other wheelchair sports as seen by the volume low volume of research published to date. Because of the velocity limitations while hitting the serve and ground strokes from a seated position, accuracy plays a larger role in wheelchair than it does with able-bodied tennis strokes. Chair mobility (agility) also plays a crucial role in the performance of a wheelchair tennis player. There is a need to understand what factors contribute to wheelchair agility as well as a need to develop tests that are specific to wheelchair tennis movement patterns.

The purpose of this series of studies is to determine the validity and reliability of three wheelchair tennis tests concerning groundstrokes, serves and agility. Study 1 found that the modified agility test demonstrated construct validity and reliability (Elite: 12.8 ± 0.78s vs. 13.8 ± 2.0s, p=0.04; ICC 0.99 for both elite and competitive athletes). It was also found that 20-m straight-line sprint speed test (r =0.9), years of tennis experience (r =-0.5) and date of injury (r=0.33) appear to be effective in predicting agility in wheelchair tennis players. Study 2 found that the HAWTT, a test evaluating hitting accuracy while hitting from a wheelchair, demonstrated construct validity and reliability (Elite: 201.3 ± 56.3; ICC=0.9 vs. Comp: 79.8 ± 50.7; ICC = 0.9). Study 3 found that the serve accuracy test demonstrated construct validity and reliability (Elite: 190.6 ± 43.0; ICC=0.8 vs. Comp: 125.5 ± 42.7, ICC = 0.9). This knowledge will
give coaches and sport scientists the information they need to enhance performance by improving training methods and on court testing.
DEDICATION

This dissertation is dedicated to those who helped me not only with the research and manuscript process, but in the balancing of academics, tennis and life. I dedicate this manuscript to my parents Terri and Tony Enquist who provided endless support and encouragement from start to finish. I dedicate this manuscript to my fiancé Laura Thomas, who motivated me to produce my best work and supported me through the long days and nights in the research process. I dedicate this manuscript to my first mentor in academics Dr. David Senchina. David set me on the path of research, higher education and helped me realize my passion in kinesiology. Finally, I would like to dedicate this manuscript to my best man Alex Johnson. His friendship, and unwavering support through my entire collegiate education has made an large impact on my success.
# LIST OF ABBREVIATIONS AND SYMBOLS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>CP</td>
<td>Cerebral Palsy</td>
</tr>
<tr>
<td>DOI</td>
<td>Date of Injury</td>
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<tr>
<td>HAWTT</td>
<td>Hitting Accuracy Wheelchair Tennis Test</td>
</tr>
<tr>
<td>ITF</td>
<td>International Tennis Federation</td>
</tr>
<tr>
<td>IWTF</td>
<td>International Wheelchair Tennis Federation</td>
</tr>
<tr>
<td>SA</td>
<td>Sacral Agenesis</td>
</tr>
<tr>
<td>SB</td>
<td>Spinal Bifida</td>
</tr>
<tr>
<td>SCI</td>
<td>Spinal Cord Injury</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>USTA</td>
<td>United States Tennis Association</td>
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</table>
ACKNOWLEDGEMENTS

I am pleased to have the opportunity to thank my family, friends and faculty members who have supported me through this research process. I am most indebted to the chair of my dissertation, Dr. Mark Richardson, for his expert advice and council on making this manuscript the best it could be. I would also like to thank all of my committee members, Dr. Michael Esco, Dr. Michael Fedewa, Dr. Lee Winchester, and Dr. James Leeper for their invaluable support for this project.

Next, I would like to thank Lauren-Haneke Hopps for her assistance in data collection and the cooperation of the University of Alabama Adapted Athletics program. Finally, I would like to thank all the participants, many of whom traveled a great distance, to assist in the completion of my research.
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CHAPTER 1:
INTRODUCTION

HISTORY

Wheelchair tennis is considered one of the fastest growing wheelchair sports in the world. One of the key factors relating to the sport’s success is the ease of integration with able-bodied tennis. Wheelchair tennis utilizes the same ball, racquet, and court dimensions as able-bodied tennis. With the exception of the “Two-bounce rule” (wheelchair players may hit off two-bounces), competitive play can even combine able-bodied and wheelchair players on the same court.

As defined by the International Wheelchair Tennis Federation (IWTF), eligibility for wheelchair tennis requires a “medically diagnosed permanent mobility related physical disability which must result in a substantial loss of function in one or both limbs” (International Tennis Federation, 2022). Once eligibility has been established, there are four primary divisions of play including Junior, Men, Women and Quad. The Junior division is further split by gender. After the age of 18, players then play in their appropriate Men’s Open or Women’s Open divisions. The Quad Open division is designed for those athletes that have both an ambulatory and upper body impairment. The International Tennis Federation (ITF) Handbook for Quad Classification states that these athletes must have a “permanent impairment that alters the biomechanical execution of wheelchair propulsion” (International Tennis Federation, 2022).

After its creation in 1977, followed by 10 years of steady growth in both tournaments as well as competitors, a significant breakthrough occurred on Monday, October 1988. The ITF
voted to create the International Wheelchair Tennis Federation (IWTF). This moment marked the official sanctioning of the new sport. Just four years after sanctioning, wheelchair tennis became a full medal sport at the 1992 Barcelona Paralympics followed by an official tour of 11 international tournaments. Today, wheelchair tennis is included at all four Grand Slams (Australian Open, Wimbledon, US Open and French Open) with a tour of over 160 tournaments in over 40 countries (International Tennis Federation, 2022).

In the United States, the United States Tennis Association (USTA) has further expanded the competitive divisions by creating skill-based divisions for amateur competitors. In the USTA system, all competitors regardless of gender, age and injury level, compete in the A, B, C or D skill-based divisions. “A” players are the most experienced and highest skill, while “D” players are the newest and most novice competitors. The United State has a unique tournament structure where all ITF sanctioned events offer both the professional ITF open division in tandem with the amateur USTA divisions.

Wheelchair tennis has been described as an intermittent activity with players demonstrating a moderate to high level of aerobic fitness (Croft, L., Dybrus, S., Lenton, J. & Goosey-Tolfrey, V. L. 2010). Players must respond to significant physiological and skill-based challenges during match play. This results in maneuvering a sport wheelchair while anticipating and reacting to the speed and movement of the ball, as well as their opponent. The playing style of the opponent, the outdoor conditions and the court surface all contribute to the positioning and movement responses.

These variables, which are inherent in each tennis match, show the importance of mobility during wheelchair tennis. Wheelchair tennis is a dynamic sport where chair engineering, athlete wheelchair operation and racquet technique all combine to influence the athlete’s
performance. The ability to accurately and efficiently position oneself to have the greatest chance for a successful shot is of greater importance than the accuracy or power of the hit itself. However, research has shown that distance covered and average chair speeds during play are associated with highly skilled players (Sindall, P., Lenton, J. P., Tolfrey, K., Cooper, R. A., Oyster, M. and Goosey-Tolfrey V. L. 2013a).

More research concerning field-based tests of agility have been conducted for sports like wheelchair basketball and rugby. Recently, the primary physiological determinants of agility were studied in wheelchair basketball players. Results demonstrated that 20-meter (20m) sprint times and medicine ball chest pass scores were strong predictors of planned agility (Williams, E. J., Wingo, J., Richardson, M., Bishop, P., Hardin, B., Leeper, J. 2014). These findings however cannot be extrapolated to wheelchair tennis due to the sport-specific nature of movement as well as the added confounding variable of different pushing mechanics when pushing with a tennis racquet. Several studies have evaluated the effect of holding the tennis racquet while pushing to show the decrements in speed and power production (De Groot, S, Bos F., Koopman J, Hoekstra A. R. & Vegter J. K., 2017).

The most heavily researched topics in wheelchair tennis center on the cardiovascular response during match play. This likely due to the noninvasive nature of data collection and simplicity of wearable technology. Based on the current body of literature on heart rate response to match play, wheelchair tennis players exhibit average heart rate values of 124.7 ± 12.5 beats/min and max rates of 158.3 ± 14.9 during competitive play (Sindall, P., Lenton, J. P., Tolfrey, K., Cooper, R. A., Oyster, M. & Goosey-Tolfrey V. L. 2013a; Croft, L., Dybrus, S., Lenton, J. & Goosey-Tolfrey, V. L. 2010; Barfield, J. P., Malone, L. A. and Coleman, T. A. 2009; Sindall, P. et al., 2014 and Roy, J. L. et al., 2006).
Another commonly investigated parameter regarding wheelchair tennis was chair velocity and distance covered during match play. Filipcic and Filipcic (2009) published one article on the topic with Sindall et al. publishing four articles (Sindall, P., 2014; Sindall, P., 2013b; Sindall, P., 2013a; Sindall, P., 2015). These studies commonly utilized Global Positioning System (GPS) data loggers placed on the chair itself. It was found that tennis players travelled up to 3952m during live tournament play with max velocities as high as 2.78m/s.

While the above-mentioned parameters are all important to an understanding of the holistic view of the sport, there is a need for specific knowledge related to identifying the elite wheelchair tennis profile. With field tests and standards that practitioners can easily utilize both on and off court, determining wheelchair tennis potential as well as assessing training progress can be more readily accomplished.

AGILITY

Understanding the physiological determinants of agility is key to understanding the proper application of off-court training as a means of performance enhancement. There remains a need to determine which variables (e.g. speed, power, strength) are most strongly associated with agility. For wheelchair tennis, this has not yet been established. Understanding the complex interplay between these variables would aid coaches when developing training programs related to improving chair mobility.

To the authors’ knowledge, only one study has examined the construct validity of an agility test in wheelchair tennis players (Rietveld, T., Vegter, R. J. K., van der Slikke, R. M. A., Hoekstra, A. E., van der Woude, L. H. V., & de Groot, S. 2019). The researchers evaluated four different field tests that were originally focused on able-bodied tennis and wheelchair basketball. The Illinois Test, Spider tests and 20m Sprint Test do not utilize tennis court specific distances.
The Butterfly-Sprint Test did utilize court specific distances with realistic game movement patterns. Using Inertial Measurement Units (electronic device that measures force, angular rate and orientation) attached to the participants’ wheels and frame, the researchers found high inter-trial reliability and good construct validity between junior and adult players. However, with agility, there is still a lack of field tests that practitioners can use to evaluate wheelchair tennis athletes. There is also a need for an agility test that can be utilized to track improvements in performance as adults move from recreational to competitive to the elite ranks.

SERVE AND GROUNDSTROKE PERFORMANCE

Beyond agility and chair skills, two additional primary considerations concerning performance are ball velocity and ball accuracy. If a ball is hit with greater velocity, there is a greater chance that an opponent is unprepared for the ball (forced error) or that an opponent will be out of position and unable to reach the ball (winner). Accuracy can be defined as the ability to place the ball in a specific location on the court. With accurate ball placement, players can dictate points and limit the number of options an opponent has. There is an inherent trade off with accuracy and velocity. While it is possible to exhibit both accuracy and velocity in shot selection, greater ball and racquet speeds increase the chances of an error. When it comes to shot selection, a player often must make the split-second decision to favor accuracy and consistency, or velocity and risk (Gerchak & Kilgour, 2017).

There are several clear differences between able-bodied and wheelchair tennis players. Abled bodied players win a high percentage of their points on the first serve, make fewer double faults, and earn fewer break points (Sanchez-Pay et al., 2015). A recent study analyzing wheelchair tennis shot selection reported that ground strokes made up more than 43% of all shots in a set. Additionally, winning players hit 62.5% more winning ground strokes (Sanchez-Pay et
al., 2017). This emphasizes the importance of groundstroke accuracy in wheelchair tennis players. Several authors have attempted to test hitting accuracy in able-bodied players (Davey et. al, 2002; Ferrauti and Weber 1998; Ferrauti and Weber 1997). The vast majority of these studies utilized a ball machine to standardize ball delivery to a specific court location as a target (Davey et. al, 2002; Davey et. al, 2003; Ferrauti et. al, 2001; Wang et. al, 2004; Spaepen et. al, 1998).

The serve is a particularly interesting aspect of the wheelchair tennis game. The serve target and start position are nearly identical to that of able-bodied tennis matches. The primary difference with wheelchair tennis is that the serve is performed from a seated position without the biomechanical advantages of lower body propulsion. Only Cavedon, C., Zancanaro, C. and Malanese, C., (2014) have reported the service velocities of wheelchair tennis players. In this study, 31 Men’s Open players performed 10 successful flat serves and 10 successful kick serves (spin). Participants were split into 4 groups with a descending level of activity limitation. Participants in groups A, B and C had complete spinal cord injuries (A, T1-T5; B, T6-T10; C, T11-L3) while participants in group D were all able to stand or walk with aids. For flat serves, participants in group A averaged 56.6 ± 5.1 mph compared to 66.4 ± 4.6 mph in group D. On kick serves group A averaged 46.4 ± 6.1 mph compared to 59.1 ± 9.5 mph recorded with group D. The authors concluded that as the severity of impairment decreases, the mean post-impact ball velocity increases. Cavedon et. al attributed the primary findings to the biomechanical difference in ball contact height and shoulder angle at ball impact. This further explains why able-bodied tennis players are able to utilize the biomechanical advantages of contact height and shoulder angle to generate greater ball velocities (Reid M., Elliott, B. and Alderson, J. 2007).

It should be appreciated that serve proficiency is considered a key factor for the success in an able-bodied match. In most cases, if the returner were to win the game, it is referred to as
“breaking” the server. Sanchez-Pay recorded and analyzed 16 professional men’s singles matches to find that 30% of all shots in a match were serves. When looking at how service points were won and lost, the authors reported a ratio of 2.7 aces to 11.8 double faults (Sanchez-Pay, A., Torres-Luque, G. & Sanz-Rivas, D., 2017). This statistic coupled with the knowledge of the biomechanical challenges of creating high horizontal velocities raises the question; Is serving in wheelchair tennis an advantage?

Success regarding able-bodied serve placement has been shown to be related to the ability to serve to the edges of the serve box (i.e. “Wide” or “T” serves) away from a returner (Hizan, Whipp and Reid, 2015). In wheelchair tennis, the mobility of a returner is limited and there is a higher probability that a player will be in a poor position to return the ball. A body serve is therefore an effective choice due to the greater likelihood that the returner will not have time to properly set up. This increases the effectiveness of a serve into the body as compared to able-bodied tennis players. Increasing one’s ability to vary serve placement can decrease the likelihood of a successful return from an opponent.

A wealth of information is available concerning able-bodied tennis serves, but few studies have analyzed the service game from a wheelchair (Cavedon, 2014; Reid, 2017). This lack of knowledge leaves technical instruction largely intuitive. Also unique to wheelchair tennis is the existence of varying levels of disability. For instance, decreased shoulder and wrist mobility associated with higher levels of disability have been found to impact serve velocities (Cavedon, 2014). Velocity and accuracy are both important contributors to a server’s success as the higher velocities decrease the returners preparation time while accuracy increases chances of hitting aces.
PURPOSE

The purpose of this series of studies was to create a battery of tests that analyze tennis serve and groundstroke performance specific to wheelchair tennis players as well as to evaluate the anthropometric and physiological determinants of agility in wheelchair tennis players.

*Study 1*: The purpose of study 1 was to determine if descriptive, anthropometric and upper body power characteristics predict wheelchair tennis specific agility.

*Study 2*: The purpose of study 2 was to determine the test-retest reliability and construct validity of the Hitting Accuracy Test in wheelchair tennis players.

*Study 3*: The purpose of study 3 is to determine the test-retest reliability and construct validity of the Serve Accuracy Test in wheelchair tennis players.

HYPOTHESES

Study 1. The Hypotheses for Study 1 are:

1) Agility times will be faster for elite compared to competitive wheelchair tennis players.

2) Wheelchair Tennis T-Test Agility times will be related to descriptive variables (date of injury, previous sport experience, number of years playing tennis), anthropometric variables (seated height, weight), upper body strength and power variables (rotational power and grip strength).

Study 2. The Hypotheses for Study 2 are:

1) Hitting Accuracy Test scores will be higher for elite compared to competitive wheelchair tennis players.

2) The Hitting Accuracy Test will be reliable in wheelchair tennis tournament players

Study 3. The Hypotheses for Study 3 are:
1) Serve Accuracy Test scores will be higher for elite compared to competitive wheelchair tennis players.

2) The Serve Accuracy Test will be reliable in wheelchair tennis tournament players

Significance of the Study

Movement in competitive wheelchair tennis is multidirectional and intermittent with a high number of directional changes (Roy et al., 2006). Wheelchair tennis is much less understood than other wheelchair sports (i.e. rugby, basketball) and there is a need to better understand training and performance factors that make elite players elite. Evaluating reliability and construct validity of the modified t-test of wheelchair agility, hitting accuracy test, and serving accuracy test will give coaches a better ability to assess tennis specific chair mobility and court performance. Additionally, evaluating those factors related to wheelchair tennis agility will further give coaches and sport scientists the information they need to enhance performance by improved training methods (Croft et al., 2010; Roy et al., 2006). Wheelchair tennis specific field tests on and off the court are necessary to improve performance in wheelchair tennis athletes.
REFERENCES


CHAPTER 2:
VALIDITY AND RELIABILITY OF THE WHEELCHAIR TENNIS AGILITY T-TEST AND EVALUATION OF THE FACTORS THAT INFLUENCE AGILITY IN WHEELCHAIR TENNIS

ABSTRACT

Wheelchair tennis involves multi-directional movements with both planned and reactive movements. Success in match play is often attributed to the court distance covered and the maximal speed achieved during play. Currently there are few agility field tests established specific to movement in wheelchair tennis. Therefore, the purpose of this study was to: 1) modify the tennis t-test utilized in able-bodied tennis to establish a new wheelchair tennis specific agility t-test, and 2) determine if descriptive, anthropometric, and upper body power characteristics predict wheelchair tennis specific agility. Twenty-four wheelchair tennis players (28.3 ± 7.4 yrs) participated in the study with the minimum requirements that they trained at least once a month and must have participated in a sanctioned ITF or USTA tournament within 24 months. Participants were further split into two groups of 12 elite participants (7 men, 5 women) who had competed in the international ITF professional divisions and 12 competitive participants (7 men, 5 women) who play only national level tournaments. Anthropometric (i.e., weight, seated height), performance measures (isometric grip strength, medicine ball chest and lateral throws, 20-m sprint), descriptive variables (years participating in tennis, years competing in tennis, tournaments played each year, tournaments played in the last two years, average hours training per week, average training hours during the competitive season, average training hours
during off season, date of injury) and agility (wheelchair tennis agility t-test) were assessed. Elite participants completed the test in an average of 12.8 ± 0.8sec while competitive participants completed in 13.9 ± 2.1sec, p<.05. The results indicated that the modified wheelchair tennis t-test is both reliable (ICC=0.99) and showed construct validity in elite and competitive wheelchair tennis players. The results also indicated that 20-m sprint (r=0.87, p<0.05) and medicine ball chest throw (r=-0.64, p<0.05) showed the strongest association with agility in elite and competitive wheelchair tennis players.

INTRODUCTION

Success in wheelchair tennis is largely dependent on the players ability to maneuver the wheelchair. To successfully maintain a multiple ball rally in tennis, a player must have agility to recover from each shot to a neutral position and then use agility to correctly set up for each shot. This requires both speed and power to maneuver a chair effectively. This is arguably the most important aspect of success as it relates to elite verses competitive athletes.

A wide variety of wheelchair tennis agility field tests are in use but very little has been published on the topic (Sanchez-Pay A. and Sanz-Rivas, D., 2020; Rietveld, T., Vegter, R. J. K., van der Slikke, R. M. A., Hoekstra, A. E., van der Woude, L. H. V., and de Groot, S. 2019). A small body of literature exists on wheelchair basketball agility tests (Williams et al., 2014; De Groot S., Balvers I.J., Kouwenhoven, S. M., & Janssen, T. W. 2012) but these are specific to wheelchair basketball as they incorporate full stops and only occasionally, backwards movements. Compared to wheelchair basketball, wheelchair tennis movement is continuous with greater side-to side movement over straight-line acceleration. Due to the difference in these sport specific agility patterns, these tests are not directly comparable.
The agility t-test utilized with able-bodied tennis players has been validated and widely used for field testing (Pauole, K, Madole, K, Garhammer, J, Lacourse, M, and Rozenek, R, 2000). The t-test has also been modified by incorporating other sport specific distances to serve a wider range of uses (Sassi, R. H., Dardouri, W., Yahmed, M. H., Gmada, N, Mahfoudhi, M. E., Gharbi, Z, 2009). These t-tests designed for able-bodied athletes incorporate linear sprints, side shuffling and in some cases a back pedal. Due to a lack of lateral and infrequent reverse (pull back) movement while playing in a wheelchair, these tests cannot be replicated in a wheelchair. Developing an agility test that incorporates both tennis specific distances and movement patterns that are consistently seen in match play will be useful to athletes, coaches, and trainers.

In addition to having a reliable and valid measure of wheelchair agility, knowing the potential factors that influence agility is also important. Factors such as anthropometric characteristics, upper-body strength, and power and speed should be considered in relation to agility.

The purpose of this study was to determine the reliability and construct validity of a modified t-test of wheelchair tennis agility and determine which factors are associated with agility. We hypothesized that:

1) Agility times will be faster for elite compared to competitive wheelchair tennis players and will be reliable (ICC > 0.75)

2) Agility will be inversely associated with descriptive variables (age, years playing wheelchair tennis, average hours training per week, average training hours during competition season, average training hours during off season, years of competition experience, average competitions per year, average competitions in the past 24 months)
3) Agility will be positively associated with anthropometric variables (seated height, weight)

4) Agility will be inversely associated with strength and power variables (grip strength, medicine ball chest throw, medicine ball forehand rotational throw, medicine ball backhand rotational throw)

5) Agility will be positively associated with straight-line speed

**METHODS**

*Experimental Approach to the Problem*

Participants attended two testing sessions completed on a single day of data collection. Upon arrival, participants reviewed the University of Alabama approved informed consent and provided consent. Participants also completed the Physical Activity Readiness Questionnaire (PAR-Q) and a wheelchair tennis history questionnaire (Appendix A). After the necessary paperwork was completed, anthropometric and performance measures were assessed. Once completed, participants performed the Wheelchair Tennis Agility T-test and returned to the tennis courts for testing session 2. The two test-retest sessions were separated by a minimum of 20 minutes with a maximum of 24hrs (mean = 45.2 ± 80.5 min; range 20 min to 6 hours).

*Participants*

Twenty-four wheelchair tennis players aged 28.3 ± 7.4 yrs participated in the study. All wheelchair tennis players met the study requirements of training on court at a minimum of once a month and had participated in a wheelchair tennis tournament within the last 24 months. Twelve participants (7 men, 5 women) were categorized as elite (have competed in a professional ITF tournament) and 12 participants (7 men, 5 women) were categorized as competitive (have competed in a USTA tournament but never a professional ITF tournament).
### Table 2.1. Individual Participant Profiles

<table>
<thead>
<tr>
<th>Group</th>
<th>Disability</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>DOI (yrs)</th>
<th>Years Playing Tennis (yrs)</th>
<th>Years Competing (yrs)</th>
<th>Average Training In-Season (hrs/wk)</th>
<th>Average Training Out-of-Season (hrs/wk)</th>
<th>Average Competitions Per Year</th>
<th>Competitions In The Last 2 Years</th>
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</table>

SA – Sacral Agenesis
SCI – Spinal Cord Injury
CP – Cerebral Palsy
Bi-Lat Amp – Bi-lateral Amputee
DOI – Date of Injury

SB – Spina Bifida
hrs/wk – Hours per Week

17
Procedure

Testing protocols were explained to each participant and informed written consent was obtained. Following consent, a 24-hour questionnaire and sport history questionnaire was administered. Participants used their own sports wheelchair to perform all testing in this study. Tire pressure was measured and if lower than 758kPa, additional air was added up to 110psi. Participants were allowed to consume fluids before and during the test at their discretion. If requested, participants were given their test scores at the end of the session.

Upon completion of both questionnaires and anthropometric tests, participants were lead through a 10-minute dynamic warm-up. Following the warm-up, participants completed anthropometric and performance tests as well as the modified agility t-test in the following order:

**Test 1: Weight (kg)**

If the participant was an “everyday wheelchair user,” they were asked to transfer to a stationary chair so that their everyday chair can be weighed and recorded by itself. Once the chair weight had been recorded in kg to the nearest 0.01 decimal place, the participant was weighed while sitting in their everyday chair. The difference in measurements was recorded for the participant weight in kilograms. If the participant was not an everyday wheelchair user, they were encouraged to stand or sit directly on the floor scale (Prime Scales, Class III Nmax 5000) with weight recorded in kilograms.

**Test 2: Seated Height (cm)**

The participants were measured in their sports chair with a “match ready” set up (all straps tightened). Participants were instructed to reach up with their dominant arm (racquet hand), as high as possible. The vertical seated reach height was measured in centimeters to the
0.01 decimal place, from the ground to the distal tip of the third metacarpal (Apollo Precision Tools, Measuring Tape).

Test 3: Grip Strength (Procedure adapted from Sale 1991)

Participants were seated in their sport wheelchair with their head facing straight ahead and their arms at their side. Participant’s elbow was set at any angle between 90° and 180° (from a right angle to straight) at the side of the body. Participant’s wrist and forearm were in a mid-prone position. Participants were asked to squeeze the hydraulic hand dynamometer (PC 5030J1, Jamar, Boling Brook, IL) maximally following these instructions: “Are you ready?,” followed by “Squeeze as hard as you can.” As the participant began to squeeze, the following instructions were given: “Harder!...Harder!...Relax.” Participants completed 2 trials with each hand (alternating hands after each trial), with at least 30 - 60 second rest between trials for the same hand. The best scores from each hand were summed to estimate total grip strength score (kg). Study personnel ensured the dynamometer was reset to zero after each trial.

Test 4: Medicine Ball Chest Toss (Clemons, Campbell, Jeansonne, 2010)

Participants were seated and strapped into their sports chair with their front and back casters stabilized with weights (45lbs plates) to decrease movement during the toss. Participants started with their backs in contact with the backrest of their chair. Study personnel instructed participants to hold the medicine ball with their hands on either side of the ball, similar to the start of a chest pass. Their forearms were positioned parallel to the ground. An 8kg medicine ball (BCG 2.0 8lbs Medicine Ball) was used for all participants. Participants were instructed to throw the medicine ball, using a chest past, as far and straight as possible. The participants back did not have to remain against their backrest. A tape measure (Keson Industries 50M Tape) was secured to the court starting from the front casters. The distance where the ball hits the court first was
recorded to the nearest cm. Participants had 2-min of rest between each throw and were allowed one practice throw (total of 4 throws). The best result of three throws was be used in data analysis.

*Test 5: Medicine Ball Rotational Toss*

Participants were seated and asked to strap into their sports chair with the chair positioned at a 90-degree angle to the throw lane. Casters were stabilized with weights (45lbs plates) to decrease movement during the toss. Study personnel instructed participants to hold the medicine ball with their hands on either side of the ball with arms extended. An 8kg medicine ball (BCG 2.0 8lbs Medicine Ball) was used for all participants. Participants were instructed to throw the medicine ball while rotating as far and straight as possible. The participants back did not have to remain against their backrest and were allowed a counter movement. A tape measure (Keson Industries 50M Tape) was secured to the floor starting from the front casters. The distance to where the ball hit the floor first was recorded to the nearest cm. Participants were allowed 2-min of rest between each throw and were allowed one practice throw. The best result of three throws on each the forehand and backhand side was used in data analysis.

*Test 6: 20m Sprint*

Participants started from a stationary position with their front casters just behind the start line (figure 2). Study personnel conducted a verbal countdown of “One, Two, Three, GO!”. Upon hearing “GO!”, participants were instructed to push the 20m as fast as possible. Infrared timing gates were set up at the start line and 20m distance. The trial time began as soon as the start command was completed and the manual start button was pressed on the timing gate system. The time was recorded after the finish line gate was crossed. Participants were be given one
familiarization trial with three recorded attempts. An attempt was considered null if the start was not stationary or if the participant deviated from the sprint lane.

Figure 2.1. 20-m Sprint Test Set Up

**Test 7: Wheelchair Tennis Agility T-Test**

The Wheelchair Tennis Agility T-Test was modified from the Tennis T-Test most commonly used with able-bodied tennis players. Cones were set up on the tennis court in correspondence to the baseline and service lines (figure 2.1). Participants sprint from the baseline to the service line (5.5m) starting at the right side of the start cone. They then weaved around the left cone on the intersection of the service line and singles line (4.1m) then weaved across to the right cone (8.2m). After the last turn participants returned to the center and exited the test on the left side of the start cone.

The researcher demonstrated the agility pattern in a wheelchair at 50% speed. The participant was asked to perform a practice push at 50% of full speed to decrease the chances of an incorrect turn. Participants started from a stationary position with their front casters on the start line. Participants began at a self-determined time as the timing gates were triggered automatically once the beam was crossed (Brower, Draper, Speedtrap II). The objective was to complete the pattern and travel back through the start gate in the shortest amount of time. The
test was considered null if the participant deviated from the pattern, made contact with a cone, or did not start from a complete stop.

Participants completed one familiarization trial and three performance trials (all trials starting on the right). All three trials were recorded with the fastest time recorded as best time. Participants were given two minutes rest between trials to ensure recovery. Participants performed the test without holding a racquet. To analyze reliability, participants were re-tested on all agility protocols after a 20-minute rest period. In total, participants were asked to complete two familiarization and six performance trials.

Figure 2.2. Wheelchair Tennis Agility T-Test Set Up

Statistical Analysis:

Construct validity was assessed based on the premise that elite tennis players possess greater agility than competitive players, and therefore would have lower test times. Independent t-
test was used to analyze the mean difference in wheelchair agility scores between elite and competitive wheelchair tennis players.

Pearson’s Correlations were used to evaluate the association between agility and: age, previous sport experience, and number of years playing wheelchair tennis, seated height, weight, speed, upper body power and rotational power and agility. The strength of the association was qualitatively described as weak, moderate, strong using the threshold values of 0.2, 0.5, and 0.8, respectively (M. M., Mukaka, 2012). Data are reported as mean (M) and standard deviation (SD) unless otherwise indicated. All hypothesis tests used an alpha level of 0.05. Statistical analysis were performed using the Statistical Package for Social Sciences [SPSS, version 27, Chicago, IL].

RESULTS

Participants recruited (28.3 ± 7.4 yrs) had played tennis for an average of 8.6 years, had been competing for an average of 7.1 years and played an average of 4.5 competitions per year.

Table 2.2 shows the results of anthropometric power and strength test results for elite vs competitive groups. No significant differences were found in these measures between elite and competitive players.
Table 2.2. Anthropometric, power and strength measures for elite and competitive players

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>M</th>
<th>SD</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grip Strength (kg)</td>
<td>Elite</td>
<td>75.8</td>
<td>16.8</td>
<td>0.09</td>
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<td></td>
<td>Competitive</td>
<td>70.7</td>
<td>25.9</td>
<td></td>
</tr>
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<td>20-m Sprint (s)</td>
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<td>0.5</td>
<td>0.09</td>
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<td></td>
<td>Competitive</td>
<td>6.3</td>
<td>0.9</td>
<td></td>
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<tr>
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<td>Elite</td>
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<td>1.2</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
<td>4.9</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>MB Forehand (m)</td>
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<td>1.3</td>
<td>0.26</td>
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<tr>
<td></td>
<td>Competitive</td>
<td>4.4</td>
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<td>1.5</td>
<td>0.20</td>
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<tr>
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</tr>
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<td>Reach Height (cm)</td>
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<tr>
<td></td>
<td>Competitive</td>
<td>179.6</td>
<td>14.8</td>
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</table>

MB = Medicine Ball
M = Mean
SD = Standard Deviation

Table 2.3 describes training characteristics for elite and competitive participants. The elite group trained more hours during the in-season and during out-of-season (both <.05). The elite group also had been competing in tournaments longer, participated in significantly more yearly competitions and had played in significantly more competitions in the last 2 years than the competitive group (both <.05). Years of tennis experience (i.e., years playing tennis) was the only variable that was not different between groups.
Table 2.3. Training characteristics for elite and competitive players

<table>
<thead>
<tr>
<th>Variable</th>
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<th>SD</th>
<th>Sig.</th>
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<td>Average Weekly Training IN (hrs)</td>
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<tr>
<td>Average Weekly Training OUT (hrs)</td>
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<td>4.1</td>
<td>&lt;.001</td>
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<td>Competitive</td>
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</tr>
<tr>
<td>Years Competing (yrs)</td>
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<td>4.8</td>
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<td>Average Yearly Competitions</td>
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<td>4.4</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Average Competitions Last 2 Years</td>
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<td>10.8</td>
<td>9.4</td>
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<tr>
<td></td>
<td>Competitive</td>
<td>2.8</td>
<td>1.9</td>
<td></td>
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</table>

IN = Refers to the in-season when competitions are frequent
OUT = Refers to the off-season when competitions are not frequent
MB = Medicine Ball
M=Mean
SD=Standard Deviation

Participants’ wheelchair configuration measurements are included in Table 2.4. Rear seat height (p=0.02) and wheel size (p=0.02) were both higher in Elite players. No differences were found between elite and competitive players for front seat height and chair weight.
Table 2.4. Participants’ wheelchair configuration measurements

<table>
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<td>Competitive</td>
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</tr>
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<td>Rear Seat (cm)</td>
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</tr>
<tr>
<td>Chair Weight (kg)</td>
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<td>0.8</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
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<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Wheel Size (inch)</td>
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<td>25.3</td>
<td>0.6</td>
<td></td>
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</table>

M=Mean  
SD=Standard Deviation

The results of the reliability and construct validity analyses are shown in Table 2.5. It was found that for both elite and competitive players the agility test demonstrated high relative reliability (ICC >0.9). The independent sample t-test indicated that elite players completed the agility test significantly faster than competitive players (p<.001).

Table 2.5. Reliability and construct validity measures for the Wheelchair Tennis Agility T-test in elite and competitive wheelchair tennis players.

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<th></th>
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<td>SD</td>
<td></td>
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<td>SD</td>
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<td>0.99</td>
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<td>14.0</td>
<td>2.2</td>
<td>0.99</td>
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<tr>
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<td>1.6</td>
<td></td>
<td>13.4</td>
<td>1.8</td>
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</table>

*p<.05, elite vs competitive  
ICC = Intraclass Correlation Coefficient

Correlation analysis (Table 2.6) indicated that 20-m sprint, grip strength, medicine ball chest pass, medicine forehand throw and medicine ball backhand throw were significant
predictors of agility performance. Reach height and participant weight were not significant predictors of agility.

Table 2.6. Pearson correlation matrix of agility times, grip strength, 20-m sprint time, medicine ball throws (chest, forehand, backhand), participant weight and sitting reach height for elite and competitive participants.

<table>
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<tr>
<th></th>
<th>Agility</th>
<th>Grip</th>
<th>20-m Sprint</th>
<th>MB Chest</th>
<th>MB Forehand</th>
<th>MB Backhand</th>
<th>Weight</th>
<th>Reach Height</th>
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<tr>
<td>20-m Sprint</td>
<td>0.87*</td>
<td>-0.76*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB Chest</td>
<td>-0.64*</td>
<td>0.81*</td>
<td>-0.82*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB Forehand</td>
<td>-0.53*</td>
<td>0.75*</td>
<td>-0.70*</td>
<td>0.92*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB Backhand</td>
<td>-0.49*</td>
<td>0.68*</td>
<td>-0.65*</td>
<td>0.96*</td>
<td>0.96*</td>
<td>-</td>
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<td></td>
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<tr>
<td>Weight</td>
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<td>0.47*</td>
<td>-0.35*</td>
<td>0.66*</td>
<td>0.66*</td>
<td>0.75*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Reach Height</td>
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<td>0.67*</td>
<td>-0.53*</td>
<td>0.72*</td>
<td>0.72*</td>
<td>0.73*</td>
<td>0.70*</td>
<td>-</td>
</tr>
</tbody>
</table>

*Significant at P<.05.

Grip = Grip Strength
MB = Medicine Ball

Table 2.7 shows the relationship between the agility test times and the descriptive predictor variables. Pearson correlations indicated that the number of years playing tennis, years competing in tournaments, average annual competitions entered, and average competitions played in the past 2 years were significantly associated with participants’ agility times. Date of injury and estimated weekly training (hours during in-season, hours during out-of-season) were not significant predictors of agility.
Table 2.7. Correlations of predictors for elite and competitive participants obtained in the tennis history questionnaire.

<table>
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<th>Sig.</th>
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<td>Date of Injury</td>
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<tr>
<td>Average Weekly Training OUT</td>
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<tr>
<td>Years Competing</td>
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<tr>
<td>Average Yearly Competitions</td>
<td>-0.39</td>
<td>0.03</td>
</tr>
<tr>
<td>Average Competitions 2 Years</td>
<td>0.39</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Anthropometric, power and strength measures showed high multicollinearity. This was also evident in the variables describing previous wheelchair tennis experience. The high multicollinearity compounded with a small sample size excluded the use of further statistical testing using multiple regression.

**DISCUSSION**

The test-retest reliability and construct validity of the Wheelchair Tennis Agility T-test were assessed in elite and competitive wheelchair tennis players. The reliability analyses showed a very high reliability between sessions 1 and 2 for both elite and competitive wheelchair tennis players. Construct validity of the agility test was also demonstrated with elite players displaying significantly faster times. The validity analysis indicated that the proposed test can be used to evaluate the court agility for different levels of wheelchair tennis players. Specifically, the agility test can distinguish between competitive (only compete in national level tournaments) and elite (compete at international level tournaments) wheelchair tennis players.
Other agility tests performed on wheelchair tennis players have found similar results to those discovered in this study. Rietveld et al., reported that four different agility tests (20-m sprint, spider test, butterfly sprint test, and Illinois test) were reliable and demonstrated construct validity when comparing high level junior and adult wheelchair tennis players. Using the same four agility/speed tests, another set of researchers found that higher level wheelchair tennis players performed better in agility without a racquet versus with a racquet during propulsion (D’Elia, F., Esposito, G., D’Isanto, T., Altavilla, G., & Raiola, G., 2021). Another researcher demonstrated reliability for a modified t-test in elite athletes and analyzed factors such as court surface which may impact agility performance (Sanchez-Pay, A., and Sanz-Rivas, D., 2021).

While comparisons of wheelchair specific agility tests are challenging to make due to the lack of literature, the 20-m sprint test has been more commonly used in wheelchair tennis research. Using four, high-level wheelchair tennis players from Spain, researchers found mean 20-m sprint time to be 7.2 ± 1.1sec (Sanchez-Pay, A., and Sanz-Rivas, D., 2021). This is slightly slower than the average 20-m sprint times for both competitive (6.3sec) and elite (5.8sec) wheelchair tennis players found in the current study. A larger study by Rietveld et al., used 21 elite wheelchair tennis players who also completed a 20-m sprint test. Participants posted an average time of 6.7 ± 0.9sec, which was close to the completion times found in the current study. Another study in Italy utilized 10 wheelchair tennis players to determine the difference in completing the 20-m sprint test pushing with and without a racquet. They found average 20-m sprint times of 7.3sec (with racquet) and 6.8sec (without a racquet).

The results of the current study indicate that 20-m sprint is a significant predictor of agility performance. The fact that the 20-m sprint was shown as a predictor of agility performance stresses the importance of accelerating verses solely reaching top speeds. This is
likely even more important for wheelchair tennis as top speed is rarely reached due to the relatively short sprint distances. In wheelchair tennis, the most effective propulsion is when the maximal speed is achieved in the least number of pushes (Goosey-Tolfrey. V, 2005; Goosey-Tolfrey V., and Leicht, C. A., 2013; Theisen & Daley, 2001).

After 20-m sprint, medicine ball chest pass and forehand rotational throw were the next strongest predictors of agility. Conversely, weight, height, and hand grip strength are not strong predictors of agility performance in wheelchair tennis players. These findings are consistent with other research analyzing agility in elite and competitive wheelchair tennis and basketball players (Sanchez-Pay, 2021, Williams, et al., 2014). Interestingly, Sanchez-Pay found that an overhead medicine ball throw was highly correlated to rank in elite wheelchair tennis players. This may indicate that the service motion is a better predictor of performance than forehand or backhand rotational throws. Since disability and function were not assessed in the current study, an overhead medicine ball throw would be a good future indicator of function and potential performance (Sanchez-Pay, 2021).

When analyzing the tennis specific descriptive predictors, our results indicated that the number of years of participating in tennis, years competing in tennis, tournaments played each year, and tournaments played in the last 2 years were predictors of agility. It is well established that agility in tennis (able-bodied) is related to years of sport specific training (Mujika, I., Sanisteban, J., Impellizzeri, F. M. & Castagna, C., 2009; Sood, H, 2013). In the present study, the elite group reported 10.2 ± 3.0 years of tennis experience, whereas the competitive group reported an average of 7.1 ± 6.6 years. The strongest correlation of the descriptive predictors to agility was the number of years participants had been playing tennis (r=-.5).
Other factors that were found not to be predictors of agility were average hours training per week, average training hours during the competitive season, average training hours during off season and date of injury. As shown in table 2.3, it is noteworthy to see that elite players recorded significantly higher volumes for all training and competition related categories. Elite players trained three times longer than competitive players, played in twice the number of tournaments per year, and played in 3 times the number of tournaments in the two years leading to the current study.

Twenty-meter sprint and years of tennis training were significantly related to the Wheelchair Tennis Agility T-Test. Training for speed in wheelchair athletes may be an effective method for improving agility and therefore improving court coverage during match play. Linear speed may also compensate for weakness in chair skills and therefore help to improve performance. It is clear that speed and agility are pivotal performance characteristics in wheelchair tennis and should be an area of focus for players and coaches looking to move from the competitive to elite ranks.

There are a few limitations of the current study that could be addressed in further research. With a larger sample size, it would be beneficial to compare wheelchair tennis players by rank and the division in which they compete. The current study also did not use disability or injury level to describe the differences in performance. Furthermore, since the 20-m sprint is not a linear distance players would cover at top speed during a match, comparing agility to tennis specific distances (i.e., 2.5-m or 5-m) may give more insights into the relationship between sprint speed and agility. Including these variables in future research, with a larger sample size, may give further insights into the factors that influence agility and the trainable variables that coaches can use to generate elite level athletes.
REFERENCES


CHAPTER 3:
TEST-RETEST RELIABILITY AND VALIDITY OF THE HITTING ACCURACY WHEELCHAIR TENNIS TEST

ABSTRACT

The purpose of this study was to utilize the Hitting Accuracy Tennis Test (HATT) validated by Strecker. E., Foster, E. B., and Pascoe, D. D. (2011) in able-bodied players and evaluate its utility in wheelchair tennis athletes. Currently no test exists to analyze hitting accuracy or ground stroke velocity in wheelchair tennis players. Twenty four wheelchair tennis players (28.3 ± 7.4 yrs) participated in the study with the minimum requirements that they trained at least once a month and must have participated in a sanctioned ITF or USTA tournament within 24 months. Participants were further split into two groups of 12 elite participants (7 men, 5 women) who had competed in the international ITF professional divisions and 12 competitive participants (7 men, 5 women) who play only national level tournaments. The tennis court was divided into 12 areas, with each assigned a point value based on an offensive, defensive and neutral shot ranging from 1 to 6 points. The newly developed Hitting Accuracy Wheelchair Tennis Test (HAWTT) consisted of 60 total groundstrokes directed at 4 different target zones. Ground stroke velocity was also measured and assigned a point value ranging from 0-3 points. Elite participants averaged a score of 198.4 ± 55.8 while competitive players averaged a score of 78.3 ± 49.2. The results indicated that the HAWTT is both reliable and valid in elite and competitive wheelchair tennis players including groundstroke velocity. The
HAWTT is a simple assessment that with minimal equipment, can give coaches a tool to monitor players groundstroke development.

**INTRODUCTION**

During tennis play, two primary considerations are ball velocity and ball accuracy. If a ball is hit with greater velocity, there is a greater chance that an opponent is unprepared for the ball (forced error) or that an opponent will be out of position and unable to reach the ball (winner). Accuracy is the ability to place the ball in a specific location on the court. Accurate ball placement could result in a situation whereby a player cannot complete a rally or place a ball away from an opponent (e.g. a passing or drop shot). Accuracy and control will decrease as velocity increases, causing an increase in hitting errors.

There are several clear differences between able-bodied and wheelchair tennis player match play statistics. Abled-bodied players win a high percentage of their points on the first serve, make fewer double faults, and earn fewer break points (Sanchez-Pay, A., Sanz-Rivas, D., & Torres-Luque, G, 2015). A recent study analyzing wheelchair tennis shot selection reported that ground strokes made up more than 43% of all shots in a set. Additionally, winning players in each match hit 62.5% more winning ground strokes (Sanchez-Pay et al., 2017). This emphasizes the importance of groundstroke accuracy in wheelchair tennis players.

Several authors have attempted to test hitting accuracy in able-bodied players (Davey et al, 2002; Ferrauti and Weber 1998; Ferrauti and Weber 1997). The vast majority of these studies utilized a ball machine to standardize ball delivery to a specific target (Davey et. al, 2002; Davey et. al, 2003; Ferruti et. al, 2001; Vergauwen, L., Spaepen, A. J., Lefervre, J., and Hespel, P. 1998). One particular study assessed test-retest reliability of a new tennis accuracy test (Strecker et. al, 2011). The authors employed the definition of Verauwan et al. (1998) for neutral,
defensive, and offensive shots. Neutral shots land in the center of the court at positions 2 and 4. Defensive shots land in front of the service line at positions 1 and 3. Finally offensive shots land close to the singles line at positions 5 and 6 (See Figure 2).

Currently no tests exist that specifically assess groundstroke accuracy and velocity in wheelchair tennis players. Therefore, the purpose of this study is to determine the test-retest reliability and validity of the HAWTT in wheelchair tennis players. The HAWTT requires the participants to hit 60 groundstrokes delivered from a ball machine utilizing the forehand and backhand groundstrokes towards specific targets with varying point values.

METHODS

Experimental Approach to the Problem

Participants attended 2 testing sessions completed on a single day of data collection. Upon arrival, participants reviewed the University of Alabama approved informed consent and provided consent. Participants also completed the Physical Activity Readiness Questionnaire (PAR-Q) and a wheelchair tennis history questionnaire (Appendix A). After the necessary paperwork was completed, participants underwent two test-retest sessions of the HAWTT (see below for details). The two test-retest sessions were separated by a minimum of 20 minutes with a maximum of 24hrs (mean = 45.2 ± 80.5 min; range 20 min to 6 hours).

Participants

Twenty-four wheelchair tennis players aged 28.3 ± 7.4 yrs participated in the study. All wheelchair tennis players met the study requirements of training on court a minimum of once a month and had participated in a wheelchair tennis tournament within the last 24 months. Twelve participants (7 men, 5 women) were categorized as elite (have competed in a professional ITF tournament) and 12 participants (7 men, 5 women) were categorized as competitive (have
competed in a United States Tennis Association tournament but never a professional ITF tournament).
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<thead>
<tr>
<th>Group</th>
<th>Disability</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>DOI (yrs)</th>
<th>Years Playing Tennis (yrs)</th>
<th>Years Competing (yrs)</th>
<th>Average Training In-Season (hrs/wk)</th>
<th>Average Training Out-of-Season (hrs/wk)</th>
<th>Average Competitions Per Year</th>
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<td>42.3</td>
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<td>6</td>
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<td>171.5</td>
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</tbody>
</table>

SA – Sacral Agenesis  
SCI – Spinal Cord Injury  
Bi-Lat Amp – Bi-lateral Amputee  
SB – Spina Bifida  
CP – Cerebral Palsy  
Uni-Lat Amp – Uni-lateral Amputee  
DOI – Date of Injury  
hrs/wk – Hours per Week
Procedure:

Upon arrival for testing sessions participants completed a wheelchair tennis history questionnaire (Appendix A) and 24 hour history form. Upon completion, participants underwent a 10-minute dynamic warm-up (Appendix B) followed by a 5-minute hitting warm-up with a researcher. The hitting warm-up consisted of 2.5 minutes of rallying to the forehand followed by 2.5 minutes of rallying to the backhand side. Following the warm-up, participants performed the HAWTT.

Participants were asked to hit 15 consecutive balls from a ball machine (Tennis Tutor, Sports Tutor, Inc.) to 4 target zones: (1) forehand cross-court; (2) forehand up the line; (3) backhand cross-court; backhand up the line. The feed rate was approximately every 4 seconds (setting 3.5 out of 6) and ball speed will be approximately 45mph (setting 4 out of 6) with a start position at the hub (4 feet behind the baseline). Each shot required the participant to move approximately 5 feet toward the hitting zone and recover back to the hub after each shot attempt (figure 1). Participants were allowed to hit three practice balls prior to each of the 4 target zone trials. Participants were allowed up to 60 seconds of recovery between target zones. The order of each target zone was randomized before each trial.

The court was marked with different point values according to Strecker, Foster, and Pascoe (2011). Figure 2 shows the differing point values and the grid that was placed on the court using synthetic roll down lines. Participants were able to see each zone and were shown a diagram of the point values prior to each trial. The researcher recorded where each of 15 balls landed on the score sheet depicted in Appendix A. Post-impact ball velocity was measured using a radar speed gun (Bushnell, Velocity). The total amount (combined accuracy and velocity) of points in each direction was used for data analysis.
Points were scored as follows:

- Accuracy point was awarded based on ball landing zone outlined in Figure 2
- 0.5-3.0 points will be awarded based on the following velocities:
  - 0.5 – Groundstroke between 20-30 mph
  - 1.0 – Groundstroke between 31-40mph
  - 1.5 – Groundstroke between 41-50mph
  - 2.0 – Groundstroke between 51-60mph
  - 2.5 – Groundstroke between 61-70mph
  - 3.0 – Groundstroke over 70mph

- Example: Player hits a forehand crosscourt in the 5-point zone at 42mph
  - \( (5 + 1.5) = 6.5 \) total points

Figure 3.1. Participant Side Set-Up

Figure 3.2. Researcher Side Set-Up

Statistical Analysis:

Construct validity was assessed based on the premise that elite tennis players possess greater groundstroke ability than competitive players, and therefor would have higher HAWTT
scores. Independent t-test was used to analyze the mean difference in HAWTT scores between elite and competitive wheelchair tennis players.

Reliability was assessed for total score using intraclass correlation. Reliability was qualitatively described as weak, moderate, strong using the threshold values of 0.2, 0.5, and 0.8, respectively (M. M., Mukaka, 2012). Data are reported as mean (M) and standard deviation (SD) unless otherwise indicated. All hypothesis tests used an alpha level of 0.05. Statistical analysis were performed using the Statistical Package for Social Sciences [SPSS, version 27, Chicago, IL]. Statistical significance was set at p value ≤ 0.05.

RESULTS

Participants recruited (28.3 ± 7.4 yrs) had played tennis for an average of 8.6 years, had been competing for an average of 7.1 years and played an average of 4.5 competitions per year.

Table 3.2 describes the differences in groundstroke velocities between the elite and competitive participants. The elite group hit higher groundstroke velocities (p=.01) on both total groundstrokes and groundstrokes that landed in the correct targets.

Table 3.2. Groundstroke velocity (mph) for elite and competitive wheelchair tennis players. “Average” includes the velocities of every ground stroke recorded. “Average In” includes every ground stroke that was in the correct zone and contributed to the overall score.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>STDEV</th>
</tr>
</thead>
<tbody>
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<td>Elite</td>
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<td>32.3</td>
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<td></td>
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<td>24.1</td>
<td>38.9</td>
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</tr>
<tr>
<td>Average In</td>
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<td>33.9</td>
<td>53.3</td>
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<td>Competitive</td>
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<td>24.2</td>
<td>37</td>
<td>3.7</td>
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</tbody>
</table>

*Significant at p<.05.

The results of the reliability analysis are shown in Table 3.3. Elite and competitive players the HAWTT demonstrated a high relative reliability (ICC >0.8). The results of the
construct validity assessment is shown in Table 3.3. The independent samples t-test indicated a significant difference between elite an competitive scores. That is, elite players displayed significantly higher scores on the Hitting Accuracy Wheelchair Tennis Test.

Table 3.3. Reliability and construct validity measures for the HAWTT in elite and competitive wheelchair tennis players.

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th></th>
<th></th>
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<th></th>
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<tr>
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<td>Stdev</td>
<td>Mean</td>
<td>Stdev</td>
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<tr>
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<td>56.3</td>
<td>195.5</td>
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<tr>
<td>Competitive</td>
<td>12</td>
<td>79.8</td>
<td>50.7</td>
<td>76.7</td>
<td>47.7</td>
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<td>Total</td>
<td>24</td>
<td>140.6</td>
<td>53.5</td>
<td>136.1</td>
<td>51.5</td>
</tr>
</tbody>
</table>

*Significant at p<.05.
 ICC = Intraclass Correlation Coefficient

DISCUSSION

The test-retest reliability and construct validity of the Hitting Accuracy Wheelchair Tennis Test were assessed in elite and competitive wheelchair tennis players. The reliability analyses showed high reliability between sessions 1 and 2 for both elite and competitive wheelchair tennis players. The construct validity of the HAWTT was also demonstrated with elite players earning significantly higher scores. The validity analysis indicated that the proposed test can be used to evaluate the hitting accuracy performance in different levels of wheelchair tennis players.

To the authors knowledge, this is the first time that the Hitting Accuracy Tennis Test (Strecker, R., Foster, E. B., Pascoe, D. D., 2011) was researched with elite and competitive wheelchair tennis players and modified to include velocity measures. Unfortunately, there are no comparative values for the groundstroke velocities of elite and competitive wheelchair tennis players found in the literature. However, groundstroke velocities from research in able-bodied tennis populations have been reported (Rota et. al, 2012). Rota et al., asked male tennis players
with 14 years of experience and who train 6 or more hours per week to hit forehands cross court out of a ball machine. The ball velocities ranged from 33-87 mph. Comparatively, our study found ground stroke velocities ranged from 32-58mph and 21-46mph for elite and competitive players, respectively.

Most studies utilizing hitting accuracy tests focused on elite able-bodied populations of NCAA collegiate athletes, nationally ranked juniors or professional ATP (Association of Tennis Professionals) tour players (Kwon, S., Pfister, R., Hager, R. L., Hunter, I., & Seeley, M. K. 2017; Terraza-Rebollo, M., & Baiget, E. 2021; Landlinger, J., Stoggl, T., & Lindinger, S. 2012). These groups have had significant training, and years of tennis experience. These highly trained athletes were able to consistently hit small targets on court with high velocities. In contrast, wheelchair tennis players often start training later in life, experience lower volumes of match play (fewer play opportunities compared to able-bodied tennis) and a wider range of technical instruction. These differences are further amplified when introducing competitive wheelchair tennis players who compete with very little coaching or technical training. For these reasons, it was imperative that the accuracy test had large hitting zones.

The current study addressed one of the important limitations of hitting accuracy tests, accounting for ball velocity. Without including velocity, it would be possible for a player to “bump” the ball to the desired target with minimal velocity while earning the same point value as an elite player. When velocity was included as a factor in the test, those who struck the ball with both high velocity and placement, earned the highest scores.

This study provides novel data on ground stroke accuracy and velocity in wheelchair tennis competitors. This test has a wide range of applications for coaches and sport scientists as a tool to assess training goals, player performance and current technical factors that influence
groundstroke velocities. Based on the results of the investigation, the Hitting Accuracy Wheelchair Tennis Test is a reliable and valid tool to assess forehand and backhand stroke performance.
REFERENCES


CHAPTER 4:
TEST-RETEST RELIABILITY AND VALIDITY OF THE SERVE ACCURACY TEST IN WHEELCHAIR TENNIS

ABSTRACT

In advanced tennis play, effective strategies and tactics are essential for successful performance. The serve is regarded as one of the most important skills for a player and therefore, a major focus of training. The purpose of this study was to create a new serve tool designed to assess a player’s accuracy and serve velocity. Currently, no such test exists that has proven to be reliable and valid for wheelchair tennis. Twenty-four wheelchair tennis players (28.3 ± 7.4 yrs) participated in the study with the minimum requirements that they trained at least once a month and must have participated in a sanctioned ITF or USTA tournament within 24 months. Participants were further split into two groups of 12 elite participants (7 men, 5 women) who had competed in the international ITF professional divisions and 12 competitive participants (7 men, 5 women) who play only national level tournaments. The serve accuracy test consisted of 30 total serves directed at six different target zones. Three zones were on the deuce court (wide, body, “T”) and 3 zones were on the advantage court (wide, body, “T”). Each serve was assigned 0-6 points based on the serve location relative to the specificized target zone. Serve velocity was also measured and assigned a point value ranging from 0-6 points. Participants were instructed to hit 5 serves to each zone (order randomized) with a maximal point value per serve of 12 points. Elite participants averaged a score of 190.6 ± 43.0 while competitive players averaged a score of 125.554 ± 42.72. The results indicated that the serve accuracy test is both reliable and valid in
elite and competitive wheelchair tennis players. The serve test is a simple assessment that coaches can use to monitor players development.

INTRODUCTION

In tennis, the serve is often thought of as the most technical aspect of a player’s game. The serve is the only stroke of the game that a player has complete control over (Bahamonde, 2000). In able-bodied tennis, the serve is thought of as an advantage due to the high post-impact ball velocities at which elite players can reach (Elliot, B. C., Marshall, R. N., & Noffal, G. J. 1995; Pugh, S. P., Kovaleski, J., Heitman, R. J., and Gilley W. F. 2003). If a returner were to win the game it is often referred to as a “break” emphasizing the expectation that the server should win the game.

Compared with able-bodied players, wheelchair players utilize fewer segments in the serve kinetic chain (i.e. legs, torso, shoulder, elbow and wrist) (Cavedon, 2014). Also, due to the wheelchair players low contact point, it is largely impractical for them to generate the same racquet velocities as their able-bodied counterparts with the same consistency and success (Reid et al, 2007). These biomechanical disadvantages resulting in lower serve velocities, make accuracy and placement of the serve a larger factor in success.

Success in able-bodied serve placement has been shown to be due primarily to placement at the edges of the serve box (i.e. “Wide” or “T” serves) away from a returner (Hizan, Whipp and Reid, 2015). In wheelchair tennis, the mobility of a returner is limited, and thus there is a higher probability of being in a poor position to return the ball. This increases the effectiveness of a body serve as compared to able-bodied tennis. Improving the ability to hit a specific zone can decrease the likelihood of a successful return from an opponent.
A wealth of information is available concerning the serve for able-bodied tennis players, but few studies (Cavedon, 2014; Reid, 2017) have analyzed the service game for a wheelchair tennis player. This lack of knowledge leaves technical instruction largely intuitive. Also, unique to the wheelchair tennis circuit is the existence of varying levels of disability. Performance limiters such as limited shoulder and wrist range of motion associated with higher levels of disability have been found to impact serve velocities (Cavedon, 2014). Velocity and accuracy are important contributors to a server’s success as the higher velocities decrease the returners preparation time while accuracy increases the chances of hitting aces.

Currently, there are no studies that have examined the velocity and accuracy of the wheelchair tennis serve. Serve accuracy tests have been performed on able-bodied tennis players but focused on the ability to serve wide in the corner of the service box (50cm from the corner) (Hernandez-Davo, 2014). In wheelchair tennis, a successful server must be able to hit a wider range of targets while maintaining the highest velocity possible with success.

A standardized assessment is needed for wheelchair tennis that examines: 1) a player’s ability to place a ball either wide, to the body or down the “T” and 2) the velocity the serves are hit with. Therefore, the purpose of this study is to evaluate the test-retest reliability and validity of a new serve tool that can be utilized during a wheelchair tennis player’s training to assess progress and improvements in serving.

**METHODS**

*Experimental Approach to the Problem*

Participants attended two testing sessions completed on a single day of data collection. Upon arrival, participants reviewed the University of Alabama approved informed consent and provided consent. Participants also completed the Physical Activity Readiness Questionnaire
(PAR-Q) and a wheelchair tennis history questionnaire (Appendix A). After the necessary
paperwork was completed, participants underwent the Serve Accuracy Tennis Test (see below
for details). Participants returned the tennis courts for testing session 2. The two testing sessions
were separated by a minimum of 20- minutes with a maximum of 24hrs (mean = 45.2 ± 80.5
min; range 20 min to 6 hours).

Participants

Twenty-four wheelchair tennis players aged 28.3 ± 7.4 yrs participated in the study. All
wheelchair tennis players met the study requirements of training on court a minimum of once a
month and had participated in a wheelchair tennis tournament within the last 24 months. Twelve
participants (7 men, 5 women) were categorized as elite (have competed in a professional ITF
tournament) and 12 participants (7 men, 5 women) were categorized as competitive (have
competed in a United States Tennis Association tournament but never a professional ITF
tournament).
Table 4.1. Individual Participant Profiles

<table>
<thead>
<tr>
<th>Group</th>
<th>Disability</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>DOI (yrs)</th>
<th>Years Playing Tennis (yrs)</th>
<th>Years Competing (yrs)</th>
<th>Average Training In-Season (hrs/wk)</th>
<th>Average Training Out-of-Season (hrs/wk)</th>
<th>Average Competitions Per Year</th>
<th>Competitions In The Last 2 Years</th>
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<td>24</td>
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<tr>
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<td>3</td>
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<td>180.3</td>
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</table>

SA – Sacral Agenesis
SCI – Spinal Cord Injury
Bi-Lat Amp – Bi-lateral Amputee

SA – Sacral Agenesis
Uni-Lat Amp – Uni-lateral Amputee

SB – Spina Bifida
CP – Cerebral Palsy

hrs/wk – Hours per Week
DOI – Date of Injury

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**Procedure**

Upon arrival for testing sessions participants completed a wheelchair tennis history questionnaire and 24-hour history form. Upon completion, participants completed a 10-minute dynamic warm-up followed by a 10-minute individual serve warm-up period. Participants were allowed to use their personal sports chair and racquet.

Three zones were marked on the court creating “Wide,” “Body,” and “T” zones (Figure 6). Zones were marked with cones on both deuce and advantage sides of the court. Players were asked to hit 5 consecutive serves to one zone before moving to the next assigned zone. Zone order was randomized amongst the 6 zones totaling 30 measured serves.

Points were scored as follows:

- 6 points awarded for a serve in the correct assigned zone
- If the serve was in the box, but not in the correct zone, the serve score was assigned the following:
  - 1 zone away – 4 points
  - 2 zones away – 2 point
- Additional points were assigned as follows:
  - 0 – serve between 0-20mph
  - 2 – serve between 21-35mph
  - 4 – serve between 36-50mph
  - 6 – serve over 51mph
- 0 points awarded for a net or out serve
- Any “let” serve was not recorded and performed again

Once the serve accuracy test was completed, participants were asked to hit 10 balls with maximum velocity to obtain serve maximum velocity. If no serves landed in the box, the maximum velocity recorded was taken from the highest velocity serve made during the accuracy test. Ball velocity was determined using a sports radar gun (Velocity Speed Gun, Bushnell). The radar gun was aligned with the server position and stationed opposite from the server in the target zone.
Figure 4.1. Serve Zone Placement. “Wide” zones are closest to the doubles alley, “Body” zones are in the center and “T” zones are closest to the center court line.

The scoring system was adjusted following analysis to the scoring system outlined above. After reviewing the data, it was evident that a greater point percentage needed to be awarded for velocity. The point breakdown utilized places equal weight on placement and velocity.

Statistical Analysis:

Construct validity was assessed based on the premise that elite tennis players possess greater serve ability than competitive players, and therefore would have higher Serve Accuracy Test scores. Independent t-test was used to analyze the mean difference in Serve Accuracy Test scores between elite and competitive wheelchair tennis players.

Reliability was assessed for total score using intraclass correlation. Reliability was qualitatively described as weak, moderate, strong using the threshold values of 0.2, 0.5, and 0.8, respectively (M. M., Mukaka, 2012). Data are reported as mean (M) and standard deviation (SD) unless otherwise indicated. All hypothesis tests used an alpha level of 0.05. Statistical analysis
were performed using the Statistical Package for Social Sciences [SPSS, version 27, Chicago, IL]. Statistical significance was set at p value \(\leq 0.05\).

**RESULTS**

Participants recruited (28.3 ± 7.4 yrs) had played tennis for an average of 8.6 years, had been competing for an average of 7.1 years and played an average of 4.5 competitions per year.

Table 4.2 describes the differences in serve velocities between the elite and competitive participants. The elite group hit with higher serve velocities (p<.001), higher serve velocities that landed in the correct targets (p<.001) and higher maximal serves (p<.001).

Table 4.2. Serve velocity descriptives of elite and competitive wheelchair tennis players. “Average” includes the velocities of every serve recorded. “Average In” includes every serve that was in the correct service box. “Maximum” equals every serve that landed in the correct service box during the max test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>STDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
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<td>46.8*</td>
<td>36.5</td>
<td>62.0</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
<td>29.7</td>
<td>20.5</td>
<td>55.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Average In</td>
<td>Elite</td>
<td>47.1*</td>
<td>36.5</td>
<td>62.0</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
<td>39.5</td>
<td>21.0</td>
<td>53.9</td>
<td>9.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>Elite</td>
<td>64.3*</td>
<td>51.0</td>
<td>78.0</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
<td>43.9</td>
<td>28.0</td>
<td>61.0</td>
<td>11.2</td>
</tr>
</tbody>
</table>

*Significant at P<.05.

In the initial serve accuracy test scoring system (up to 3 points maximum for velocity), no significant differences were found between elite and competitive players’ scores. Elite players averaged 125.0 ± 24.0 points whereas competitive players averaged 102.4 ± 39.9 points.

The results of the reliability analysis are shown in Table 4.3. It was found that for both elite and competitive players the serve accuracy test (revisited to give more weight to velocity)
demonstrated a high relative reliability (ICC >0.7). The results of the construct validity assessment are shown in Table 4.2. The independent samples t-test indicated a significant difference between elite vs competitive scores (p<.001). That is, elite players displayed significantly higher scores on the serve accuracy test. Also, total average serve velocity, average velocity of serves made in, and maximum serve velocities were all greater in elite players.

**Table 4.3. Serve accuracy score in elite and competitive wheelchair tennis players.**

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th></th>
<th>Session 2</th>
<th></th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>12</td>
<td>190.6*</td>
<td>43.0</td>
<td>183.7</td>
<td>39.0</td>
</tr>
<tr>
<td>Competitive</td>
<td>12</td>
<td>125.5</td>
<td>42.7</td>
<td>129.0</td>
<td>39.9</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>158.1</td>
<td>42.9</td>
<td>156.3</td>
<td>39.5</td>
</tr>
</tbody>
</table>

*Significant at P<.05.
ICC = Intraclass Correlation Coefficient

**DISCUSSION**

In the current study, the test-retest reliability and construct validity of the serve accuracy test were assessed in elite and competitive wheelchair tennis players. The reliability analyses showed high reliability between Sessions 1 and 2 for both elite and competitive wheelchair tennis players. Construct validity of the serve accuracy test was demonstrated in that elite players had significantly higher scores. The validity analysis indicated that the proposed test can be used to evaluate the serve performance in different levels of wheelchair tennis players.

The original scoring scheme placed a higher weight on accuracy than ball speed. The highest score possible was 6 points for accuracy and 3 points for ball velocity. Utilizing the original scoring system, elite competitors averaged 112.1 ± 24.0 points while competitive players averaged 107.2 ± 39.9 points (p=0.13). It became clear to the researchers that there was not enough weight on the ball velocity of the serve. A player could accumulate a large percentage of points by “tapping” the serve in at very low velocities. This strategy while effective in obtaining
a high score on the test, would not correlate to an effective strategy during an actual match situation. Therefore, the original scoring scheme was altered to a new scoring system where ball velocity carried more weight in the overall serve score.

The serve in able-bodied tennis is often viewed as the most dominant and powerful stroke in the game. This could also be said for the game of wheelchair tennis as it comprises nearly 30% of all strokes in professional match play (Sanchez-Pay et al. 2021). According to data analyzed in grand slam matches for able-bodied and wheelchair tennis athletes, serves are even more important in wheelchair tennis due to the low number (2-4) of shots per rally (Bullock and Sanz, D. 2010, Sanchez-Pay et al. 2015). Serve velocities from a seated position are much lower than able-bodied players of comparable ranking. With a serve velocity “ceiling” often reached due to the lack of lower-body activation in the serve kinetic chain, accuracy and placement of the serve plays a larger role in wheelchair tennis.

To the researchers knowledge, this study was the first to create a serve accuracy test incorporating both measured placements and serve velocities designed for the wheelchair tennis player. Serve tendencies have been assessed utilizing the same 3 target approach (Wide, Body, T), but was done in a post-match video analysis in elite junior able-bodied players (Hizan, H., Whipp, P., & Reid, K, 2015). Most serve studies to date have focused on serving to one specific target zone and measured the impact of various independent variables (fatigue, stress, pressure, etc.) on the ability to maintain serve accuracy (Terraza-Rebollo, M., & Baiget, E., 2020; Beckman, J., Fimpel, L., & Wergin, V., 2021; Hernandez, H., Urban, T., Sarabia, J. M., Juan-Recio, C & Moreno, F. J., 2014)

Our findings for average maximal elite serve velocity (64.3 mph) was comparable to those found in the recent literature (Sanchez-Pay et. al 2021 & Cavedon et al 2014). Sanchez-Pay
utilized a similar protocol that involved an average of 10 maximal serves. Their average serve velocities were slightly higher at 71.4 ± 6.3 miles per hour. This may be due to their participant pool as all 9 players were actively ranked ITF players in the top 150 in the world. In contrast, Cavedon studied 31 elite players and recorded the first 10 successful max serves with no limit on attempts. They found an average serve velocity slightly lower than our findings at 60.5 mph.

This study provides valuable insights into the serve performance of elite and competitive wheelchair tennis players. Based on the results of this investigation, the serve accuracy test is a simple, reliable, and accurate method to measure tennis serve performance.
REFERENCES


APPENDIX A: WHEELCHAIR TENNIS HISTORY QUESTIONNAIRE

Tennis History:

When did you first start playing wheelchair tennis

When did you first start playing able-bodied tennis (if applicable)

When did you play your first wheelchair tennis tournament

When did you play your first able-bodied tennis tournament (if applicable)

Training Routine:

1) How many average hrs/week do you currently train?

2) How many hrs/week do you train during tennis season?

3) How many hrs/week do you train during the off season?

Tournament Play:

1) How many average tournaments do you play per year?

2) How many tournaments did you played between 2019-present?

3) Which division of tournament play do you normally participate?
   Professional ITF – Men’s
   Professional ITF – Women’s
   Professional ITF – Quad
   USTA – Coed A
   USTA – Coed B
   USTA – Coed C
   USTA – Coed D
   Other _______________________________
Rank:

What is your current USTA Ranking? Rank _______ Division _______ Year ______

What was your best career USTA Ranking? Rank _______ Division _______ Year ______

What is your current ITF Ranking? Rank _______ Division _______ Year ______

What was your best ITF Ranking? Rank _______ Division _______ Year ______

Miscellaneous Information:

Which is your dominant racquet hand? Right Left
December 15, 2021

Evan Enquist
Alabama Disability Sports
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB # 21.08.4884: “Validity and Reliability of Hitting Accuracy in Wheelchair Tennis Athletes”

Dear Evan Enquist:

The University of Alabama Institutional Review Board has granted approval for your proposed research. Your application has been given expedited approval according to 45 CFR part 46. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The approval for your application will lapse on December 14, 2022. If your research will continue beyond this date, please submit a continuing review to the IRB as required by University policy before the lapse. Please note, any modifications made in research design, methodology, or procedures must be submitted to and approved by the IRB before implementation. Please submit a final report form when the study is complete.

Please use reproductions of the IRB approved informed consent form to obtain consent from your participants.

Good luck with your research.

Sincerely,

Carpantato T. Myles, MSM, CIM, CIP
Director & Research Compliance Officer

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