Wheelchair Velocity of Tennis Players During Propulsion With and Without the Use of Racquets

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To compare the velocity characteristics of wheelchair propulsion with and without the use of a tennis racquet, eight male wheelchair tennis players performed a series of 20m sprints from a stationary start. The maximum velocities reached on average $4.39 \pm 0.74$ m/s; however, they were reduced by $0.18 \pm 0.06$ m/s during the racquet condition. Furthermore, when wheeling under the racquet condition, the velocities achieved during the first three pushes were significantly reduced. The reduction in maximum velocity and relative velocity contributions while holding a tennis racquet may have been due to an ineffective push technique resulting in low effectiveness of force application. The relation of these parameters and trunk stability is discussed.

The movement dynamics of wheelchair tennis are specifically related to propelling the wheelchair while holding a tennis racquet. The specific movements of the tennis wheelchair-user interface are similar to basketball and rugby and include starting, sprinting, braking, and turning (pivoting). As with these popular multiple sprint based wheelchair sports, the wheelchair tennis player’s ability to accelerate quickly from a standstill is considered more important than sprinting (Vanlandewijck, Theisen, & Daly, 2001).

Wheelchair sport propulsion strategies are complex (Goosey-Tolfrey & Kirk, 2003). Wheelchair acceleration and sprinting ability not only depends upon the wheelchair and user, but more importantly, the wheelchair-user interface (Vanlandewijck et al., 2001; Woude, Veeger, & Rozendal, 1989). For basketball chair configurations, maximum velocities of up to 4.75 m/s and 4.08 m/s for male and female basketball players, respectively, have been reported (Coutts, 1994; Vanlandewijck, Daly, & Spaepen, 1999). One would expect these maximum velocities (MV) to be achievable by the tennis player as tennis wheelchairs typically have similar wheel dimensions and camber angles to that of a basketball wheelchair. However, the tennis racquet is an additional constraint to the wheelchair-user interface during propulsion in wheelchair tennis. Not only does this have the potential to affect MV, but more importantly, it may affect the participant’s ability to achieve a high percentage of MV over the initial pushes. It is therefore assumed that the
most effective propulsion strategy would result in obtaining MV in the least amount
of pushes possible.

The linear wheelchair and push rim velocities from a standing start have only
been studied in wheelchair basketball players (Coutts, 1990, 1994). During a sprint
test on a wheelchair ergometer, three male wheelchair basketball players achieved an
average MV of 4.02 m/s. Data demonstrated that 61% of MV was achieved during
the first push increasing to 80% of MV during the third push (Coutts, 1990). It is
important to note that this study used a stationary wheelchair ergometer, which
would have failed to address the contribution to the forward momentum of the
wheelchair brought about by the movement of the trunk and upper body (Moss,
Fowler, & Goosey-Tolfrey, 2005). Vanlandewijck et al. (2001) state that wheelchair
propulsion should be studied under realistic conditions. Recent advancements using
telemetry based velocimeters now enable us to measure wheelchair velocity under
realistic field conditions (Moss, Fowler, & Tolfrey, 2003).

Using a velocometer, the velocity characteristics of a sample of wheelchair
tennis players during wheelchair propulsion over 20m from a stationary start were
collected. The purpose of the study was to describe wheelchair velocity during the
first 3 pushes and the MV with and without the use of a tennis racquet. Furthermore,
the relationship between trunk stability and (a) the MV achieved with the racquet and
(b) the relative percentage of first push optimum was examined. It was hypothesized
that without the tennis racquet, it would be easier to maintain a proper hand-grip
and hence accelerate the wheelchair quicker from a standstill as well as obtain a
higher MV. It was further hypothesized that players with a greater degree of trunk
stability would obtain a better velocity profile.

Methods

Participants

Eight highly trained male wheelchair tennis players (34 ± 7 yrs.) volunteered to
participate in the study. All participants gave written informed consent prior to any
involvement in the study. Approval for the study procedures was obtained from
the University Research Ethics Committee. All the participants were considered
as highly trained, having competed regularly on the international tennis circuit and
being part of the National Great Britain squad in preparation for their selection for
the 2004 Paralympic Games. The disability and participant descriptive demograph-
ics are presented in Table 1. Participants used their own tennis wheelchairs, which
varied in manufacturer and design (ranges: wheel camber angles 18-20°, wheel
size 25-26 inches, and push-rim diameters 24-25 inches). Within wheelchair tennis,
only two classifications exist (quadriplegics and open). Therefore from a combina-
tion of medical records, chartered physiotherapy records, physiological test data,
observation of tennis play, and physical examination from the Great Britain Head
Physiotherapist players were ranked according to trunk stability. The participants’
final ranking (1 to 8; the higher the rank the greater the ability) agreed to the
corresponding classification system used within wheelchair rugby (International
Wheelchair Rugby Federation) and wheelchair basketball (International Wheelchair
Basketball Federation). These classification systems used focus on (a) the nature and
severity of the athlete’s disability and (b) the athlete’s functional ability to perform
skills associated with the sport. Athletes are assigned points (classification) based on
Velocity Characteristics of Wheelchair Tennis Players

their ability to perform tasks or skills associated with the game of rugby/basketball. The more points an athlete accumulates, the greater his/her ability.

Data Collection

Immediately prior to testing, a velocometer, developed at the Manchester Metropolitan University to measure changes in racing wheelchair velocity with respect to each push (Moss et al., 2003), was fitted to each participant’s wheelchair and then calibrated. After each participant completed his normal warm-up, he completed twelve maximal sprints as described. The sprints were performed from a stationary start, along a 20m section of an indoor tennis court marked from the baseline. The starting commands “three, two, one, go” were employed to initiate each trial. Trials were randomized between the conditions, “with racquet (R)” and “no racquet (NR).” When performing R trials, participants held their own tennis racquet in the usual manner, in their playing hand. Participants were allowed a full recovery between trials in order to minimize the effect of fatigue. This period was at least three minutes. During each trial, data from the velocometer were recorded using a laptop personal computer.

Data Analysis

The velocometer data were exported to a spreadsheet (Microsoft Excel XP). For each participant, the highest wheelchair velocity, reached from each condition, R (n = 6) and NR (n = 6), was defined as maximum velocity (MV). Correspondingly,

### Table 1  Participant International Wheelchair Tennis Federation (IWTF) Ranking, Disability Details, and Wheelchair Tennis Playing Experience at National Level

<table>
<thead>
<tr>
<th>Participant</th>
<th>IWTF Rank</th>
<th>Disability</th>
<th>Trunk Stability</th>
<th>Tennis Playing Experience (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top 30</td>
<td>SCI, T6 Complete</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Top 40</td>
<td>SCI, C6/C7 Complete</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Top 30</td>
<td>SCI, T3 Incomplete</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Top 25</td>
<td>SCI, C7/C8 Incomplete</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>Top 50</td>
<td>SCI, T10 Incomplete</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Top 25</td>
<td>SCI, C7 Incomplete</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>Top 130</td>
<td>Brittle Bones</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>Top 40</td>
<td>AMP, right leg above knee</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

Key. SCI = spinal cord injury and AMP = amputee. Trunk stability was established from medical and physiotherapy records.
for the analysis of the first three pushes, the average of the six trials was used for each participant. The MV achieved during the NR condition was considered to be the optimum MV since there was no constraint during wheelchair propulsion. The following mean values were derived: maximum velocities, peak velocities of pushes 1 to 3, the relative wheelchair velocity (%), which was defined as the ratio between peak velocity and MV for the first 3 pushes. Similarly the wheelchair velocity (%) relative to the MV obtained from the NR condition was calculated for these three pushes. The time to MV, total number of pushes over the 20m, and the distance the participant traveled were also calculated.

The Statistics Package for the Social Sciences (SPSS, Chicago, IL) was used for all statistical analyses. Separate condition by push (2 × 3) within measures ANOVA were used to analyze the effect of the independent variables on wheelchair velocity, distance traveled and relative percent of MV. Post-hoc tests were used to explore significant main effects across the three levels of push, whereas simple effect analyses were used to further analyze significant interactions. A paired student’s t-test was applied to assess the significance of differences in the MV, time to MV, and total number of pushes between the R and NR conditions. A two tailed \( \alpha < 0.05 \) was considered to be statistically significant. Effect sizes were calculated and corrected for small samples according to Hedges (1981) to determine the meaningfulness of the differences. An effect size > .80 reflects a large/meaningful difference, and an effect size > .50 reflects a moderate difference. The relationship between trunk stability and the maximum velocity achieved with the racquet as well as trunk stability and the relative percentage of first push optimum was examined using a Spearman Correlation.

**Results**

Figure 1 shows the velocity profile of the first 10 pushes from two selected trials (R and NR) for one wheelchair tennis player. An advantage can be observed for the NR condition, shown by greater acceleration during the first push and a higher velocity reached by the tenth push. During the NR trial, the player was also able to perform the ten pushes in a shorter time period than in the trial under the R condition.

From a group perspective, a significant main effect for condition (\( F_{(1,7)} = 22.9, p = 0.002; \) ES = 0.22) revealed that the peak velocities were lower in the racquet trials compared to the NR condition (2.08 vs. 2.28 m/s, respectively). A main effect for push (\( F_{(1,2,8,3)} = 435, p < 0.001; \) ES = 0.30) revealed that as expected, peak velocity increased across pushes. A nonsignificant condition by push interaction (\( F_{(2,14)} = 2.2, p = 0.15 \)) showed that in both conditions velocity increased by the same extent across the three pushes. This nonsignificant interaction was also found for the relative percent of MV. Figure 2 illustrates that wheelchair propulsion with the racquet significantly reduced MV by 0.18 ± 0.06 m/s (4.22 vs. 4.39 m/s; \( p < 0.01 \)). In fact, even by the third push, peak velocity was significantly restricted when holding a tennis racquet (2.48 vs. 2.73 m/s; \( p < 0.01 \)). Despite these significances, the difference between the two conditions is only marginal, which was reflected by a low effect size.

In relative terms, when holding a racquet, the players achieved 39.5 ± 15.5% of their MV during the first push increasing to 60.8 ± 14.3% after the third push (Table 2; significant main effect for push: \( F_{(1,1,7,6)} = 169, p < 0.001; \) ES = 0.22). In comparison, 63.8 ±11.3% of MV during the third push was attained under the
NR condition. However, if one considers the R condition as a percentage of the optimum velocity achievable (without a racquet; NR), then the attainable velocity after three pushes was significantly lower ($p < 0.01$) and was found to be only 58.5% compared to 63.8% ($p < 0.01$). Interestingly, despite no difference in the time to MV, the number of pushes taken to cover 20m when holding a racquet was significantly higher than under the NR condition (13.8 ± 2.1 vs. 14.3 ± 2.5; $p < 0.01$; Table 3). The mean distance covered (Table 3) shows that players were able to travel further in the trials under the NR condition than in the trials under the R
Table 2  Relative Velocity Contributions Across the First Three Pushes as a Percentage of the Maximum Velocity Achieved During the NR and R Conditions

<table>
<thead>
<tr>
<th>Condition/ Group</th>
<th>NO RACQUET (NR)</th>
<th>RACQUET (R)</th>
<th>RACQUET (Ropt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of Maximum velocity of condition</td>
<td>% of Maximum velocity of condition</td>
<td>% of Maximum velocity (Optimum)</td>
</tr>
<tr>
<td>Male (n = 8)</td>
<td>Mean</td>
<td>41.1</td>
<td>54.0</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>14.1</td>
<td>13.1</td>
</tr>
</tbody>
</table>

Note. Ropt. is calculated as the ratio between wheelchair velocity achieved under the R condition divided by the maximum velocity achieved under the NR condition. <sup>a</sup> p < 0.01 between corresponding push of NO RACQUET condition, <sup>b</sup> P = 0.07 between corresponding push of NO RACQUET condition. Effect sizes range from 0.06 to 0.22.

Table 3  Distance Covered, Total Number of Pushes to Cover 20m, and Time to Peak Velocity Over 20m Under the NR and R Conditions

<table>
<thead>
<tr>
<th>Condition/ Group</th>
<th>NO RACQUET</th>
<th>RACQUET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Push 1</td>
<td>Push 2</td>
</tr>
<tr>
<td>Distance covered (m)</td>
<td>Mean</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.05</td>
</tr>
<tr>
<td>Total number of pushes to cover 20 m</td>
<td>Mean</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.1</td>
</tr>
<tr>
<td>Time to maximum velocity (s)</td>
<td>Mean</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Note. <sup>a</sup> p < 0.01 between NO RACQUET condition. Effect size of 0.20
condition (significant main effect for condition and push; $p < 0.01$). This is hardly surprising given the increased velocity the athletes attained during the trials under the NR condition.

The relationship between MV and relative velocity contributions during the R condition in relation to trunk stability are shown in Figures 3a and 3b. There was a significant correlation in relation to trunk stability for both these variables, MV (0.84; $p < 0.01$), and the relative velocity attained after the first push (0.93; $p < 0.01$).

Figure 3a — Relative first push velocity to optimum velocity in relation to trunk stability.

Figure 3b — Maximum velocity achieved during the R condition in relation to trunk stability.
Discussion

According to our knowledge, this study is the first to provide an insight into the velocity profiles of wheelchair tennis players. The mean MV value without a racquet (4.39 ± 0.68 m/s) falls midway within previous literature (Coutts, 1990; Vanlandewijck et al., 1999). In part, differences in MV between studies may be masked by measurement techniques and testing surface employed. However, the key difference is that Coutts’ (1990) data were presented over a decade ago. Therefore, it seems logical to assume that technical advances in wheelchair design and improvements in mechanical efficiency, in conjunction with improved training regimes, can be largely responsible for these improvements in the recent MV values (Vanlandewijck et al., 2001); however, it is important to explain why wheelchair basketball players employed in Coutts’ (1990) study were more effective with accelerating their chairs. In relative terms, the basketball players reached 80% of their MV during the third push, when wheeling under similar conditions (NR), our tennis players were only able to achieve 63.8 ±11.3%. Notably, the basketball players clearly had a greater peak velocity after the first push.

Interestingly, the wheelchair velocity reported by Coutts (1990) showed that the basketball players’ velocity plateaued after 3s. In contrast, our data mirrored the profile obtained from the wheelchair distance racers whom Coutts (1990) also studied. For both the tennis players and racers, the velocity profiles were found to gradually increase over the duration of the tests. It was evident that the tennis players utilized the period following the third push to increase their velocity, compensating for a lack of acceleration. Data of this kind are important for the coach to know, particularly for this group of wheelchair tennis players, who focus on increasing their ability to improve the first three pushes, rather than increasing sprinting ability (Vanlandewijck et al., 2001).

While a comparison between Coutts’ (1990) data is possible, it is important to note that all participants were from the IWBF Class 3 sporting category (IWBF Points 3.0 and 3.5); however, our study contained a fairly heterogeneous sample with respect to disability and where relevant, with completeness of the SCI. Wheelchair tennis involves only two playing categories (quadriplegic and open). Hence, within the open division, one may find a SCI player (SCI level T3) competing against an amputee. In the present study, three players were quadriplegics. This may explain why lower peak velocities were reported for the tennis players during the initial pushes. It is well documented that for these participants, performance is hampered not only through disruption to the autonomic nervous system, but also due to reduced functional muscle mass in the trunk and upper limbs (Woude, Baker, Elkhuizen, Veeger, & Gwinn, 1998). Evidence from anaerobic wheelchair ergometry tests has shown that variations in disability, and hence the degree of trunk stability, influence power output (Bhambhani, 2002; Janssen, Dallmeijer, Veeger, & Woude, 2002) and velocity (Doyle et al., 2004) that is achievable. Supportive of these statements is that a significant relationship was found between trunk stability and relative velocity (first push) and MV during the R condition. As trunk stability plays an important role in developing anaerobic power, the relationship between lesion level and the velocity profile across a larger sample group of players warrants further investigation.

When wheeling under the R condition, the MV and peak velocities achieved during the first three pushes were significantly reduced. Even with tennis playing
experiences of > 6 yrs., wheelchair propulsion with a racquet is always likely to be slower than with NR because of the influence of the racquet weight during propulsion and recovery phases. Not only does the racquet handgrip play an important role in the control of the placement of the shot (Davey, Thorpe, & Williams, 2002), but holding a racquet while propelling a wheelchair interferes with the hand contact on the rim. Tennis players may have to rely on a high coefficient of friction between their racquet and the hand-rim, due to loss of effective grip (Gehlsen, Davis, & Bahamonde, 1990). These problems relating to coupling the hand to the rim with the racquet in the hand may be best understood through the study of force application strategies. Indeed, Linden, Valent, Veeger, and Woude (1996) examined the effects of hand-rim tube diameter on propulsion efficiency and force application and found that propulsion with a larger hand-rim resulted in an improved mechanical efficiency. Several studies have investigated the size, shape, and material of the hand-rim during standard manual wheelchair propulsion (Linden et al., 1996). Moreover, the size of the hand relative to the size of object (e.g., the tennis racquet) has been linked to grip strength (Fransson & Winkel, 1991). For wheelchair tennis players, the tennis racquet is a very specific constraint, thus it must be selected with care. The findings of the aforementioned studies need to be addressed during wheelchair sport propulsion.

Interestingly, during the R condition, it was evident that MV was achieved within a similar time to that of the NR condition (about 11s). It appears that this was made possible by athletes adopting a technique whereby a faster push frequency was employed. This adaptation in wheelchair sprinting technique of faster and shorter pushes follows coaching advice for wheelchair sprinting by Walsh (1987). An awareness of the effects of push frequency and sprinting ability upon wheeling performance on a tennis court needs to be adopted within training drills prescribed by our United Kingdom tennis coaches. There may not be a large difference in the velocity profiles between the two conditions, but from a practical perspective, covering .16m less distance after the third push may have a consequence on whether or not the ball is returned, or if it is returned, whether or not the optimum technique is permitted, allowing the player to achieve the correct racquet head angle to contact the ball (Davey et al., 2002).

Analysis of the velocity profiles across the three pushes with a without the racquet revealed the following. Wheeling with a racquet resulted in players achieving 39.5 ± 15.5% of their MV during the first push and 60.8 ± 14.3% by their third push. In comparison, 63.8 ± 11.3% of MV was achieved by the third push for the NR condition; however, if one were to consider that the MV from all 12 sprints was achieved during the NR condition, then the peak velocities relative to the optimum MV resulted in players only achieving 58.5% of optimum MV after the first push. This discrepancy may have been due to an ineffective push strategy resulting in low effective force application (Veeger, Lute, Roeleveld, & Woude, 1992), by applying the hand to the rim as described earlier. Some players experiencing a greater reduction in velocities while pushing with the racquet suggests to coaches that they should incorporate drills with the racquet at all times. This should enable players to enhance wheelchair propulsion with the racquet. Future studies could be designed to examine adaptations in kinetics and kinematics during wheelchair propulsion with a tennis racquet.

The results of this study have several important practical implications. Holding a racquet while propelling a wheelchair interferes with the contact of the hand on the
hand-rim. This was evident when MV and peak velocities achieved during the first three pushes are restricted due to the presence of a racquet ($p < 0.01$). Moreover, by the 3rd push, .16m less distance was covered, which may have a consequence of whether or not the ball is returned with an optimal technique. Further work is essential to gain a clearer understanding in order to assist coaches with training ideas designed to improve wheelchair tennis propulsion. Despite the small sample size of elite wheelchair tennis players, relationships between trunk stability and wheelchair velocity characteristics have been found. This may open debate around the fact that currently only two competitive divisions (IWTF) for wheelchair tennis players exist. Future studies profiling the physiological and biomechanical aspects across a range of wheelchair tennis participants are warranted.

References


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### Author Note

Specific technical details of the tennis wheelchairs used can be obtained via request to the author.