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Division, result and score margin alter the physical and technical performance of elite wheelchair tennis players

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Division, result and score margin alter the physical and technical performance of elite wheelchair tennis players

Original investigation

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ABSTRACT

This study determined the physical and technical demands of elite wheelchair tennis (WT) match-play, how the demands differed between divisions (Men, Women, Quad) and the effect that set result and score margin had on these demands. Seventeen WT players were monitored during a singles competition. Physical measures of performance were analysed using an indoor tracking system and inertial measurement units. Technical measures of performance were examined using video analysis. Physical measures of performance differed by division (Men > Women > Quad) for most parameters. Rallies were longer during Men's ($P = 0.027$) and Women's ($P = 0.004$) matches compared to Quad's and fewer shots were hit off 2 bounces in Men's matches compared to Women's and Quad's ($P \leq 0.026$). High-speed activity (HSA) increased during losing sets ($P = 0.043$). Most physical measures of performance increased by moderate to large effects during sets with a small score margin (≤ 3 games differential). Mean speed and HSA were similar during losing sets, regardless of margin, but decreased (large effects) when winning by a large margin. This study demonstrated the physical and technical demands that elite WT players need to be prepared for and how situational factors can influence these demands.

Keywords: Activity profiles, video analysis, disability sport, wheelchair athletes, sports performance

INTRODUCTION

Wheelchair tennis (WT) is a court-based wheelchair sport that has been included at the Paralympic Games since 1992. It is played on the same size court, using the same scoring system and rules as the able-bodied version of the sport. The only exception is that two bounces of the ball are permitted during WT and a classification system is used to categorise athletes according to the severity of their physical impairment. Athletes with a permanent lower limb impairment (e.g. lower limb amputation; spinal cord injury - paraplegia) are eligible to compete in the 'Open' division, of which a separate category exists for both men and women. Athletes with a permanent lower and upper limb impairment (e.g. cerebral palsy; spinal cord injury - tetraplegia) compete in a Quad division, where men and women compete together (International Tennis Federation, 2019).

WT has been described as an intermittent, multidirectional sport which is predominantly aerobic-based with short periods of high intensity activity interspersed (Croft, Dybrus, Lenton, & Goosey-Tolfrey, 2010; Roy, Sayers Menear, Schmid, Hunter, & Malone, 2006; Sindall et al., 2013b), and significant skill-based challenges also imposed on players during match-play (Filipic & Filipic, 2009; Sanchez-Pay, Torres-Luque, & Sanz-Rivas, 2016; Sanchez-Pay, Torres-Luque, & Sanz-Rivas, 2017). Previous research into the physical demands of WT has revealed that players typically cover distances of 2816 ± 844 m at a mean speed of 0.7 ± 0.2 m·s⁻¹ and reach peak speeds of 3.4 ± 0.4 m·s⁻¹ (Sindall et al., 2013b), with average heart rates equivalent to 66-75% of peak heart rate during singles match-play (Croft et al., 2010; Roy et al., 2006; Sanchez-Pay et al., 2016). Technical analysis has often been limited to temporal parameters, with rallies typically shown to last less than 6 secs and be completed in 3 strokes or less (Filipic & Filipic, 2009; Sanchez-Pay et al., 2016; Sanchez-Pay et al., 2017). However, much of this research has focused solely on male WT players and if female

or Quad players have been included, few comparisons have been made between the divisions. Only Sanchez-Pay et al. (2017) compared technical differences between Men's and Women's matches and revealed that rallies lasted longer during Women's matches. To individualise exercise prescription, a thorough examination of both the physical and technical demands across divisions is needed.

To further optimise the training environment, it is also important to establish which aspects of performance, both physical and technical, are most associated with successful performance in WT. Previous research has typically identified key performance indicators within sports by exploring what higher ranked or winning teams/players do differently to lower ranked or losing teams/players (Davis, Wittekind, & Beneke, 2013; Hoppe, Baumgart, & Freiwald, 2016; Rhodes, Mason, Malone, & Goosey-Tolfrey, 2015). From a physical perspective, Sindall et al. (2013a) revealed that high ranked (top 25 in the world rankings) WT players covered more distance, at a higher mean speed and reached higher peak speeds than low ranked (outside top 350 in the world rankings) players. However, a direct relationship between increased physical activity profiles and successful performance cannot be made due to the large disparity and heterogeneity between ability levels of the high and low ranked groups used. In addition, Sindall et al. (2013a) observed that match result had no significant bearing on activity profiles. Alternatively, in able-bodied sports, the result and margin of the result have both been shown to influence the physical and technical demands imposed on athletes (Gabbett, 2013; Lupo, Condello, Capranica, & Tessitore, 2012; Sullivan et al., 2014). Sullivan et al. (2014) demonstrated that although activity profiles and technical skill involvements were elevated during losing quarters of Australian football, smaller score margins also resulted in increased activity profiles yet with decreased efficiency of technical skills. Whereas larger score margins have been associated with increased physical demands

during rugby league (Gabbett, 2013). Different trends across different sports highlight the need for sport-specific research into the impact of situational variables on performance.

Subsequently, the aim of the current study was to firstly establish the physical and technical demands of elite WT players and examine how these demands differ between divisions. A secondary aim was to determine the impact of set result and score margin on these parameters. Discrepancies between divisions as well as the type of adaptation (physical or technical) could guide athletes and coaches in their match preparations.

METHODS

Participants

Seventeen international WT players (age = 30 ± 8 yrs) participated in the study and included players from the Men's (n = 7), Women's (n = 6) and Quad (n = 4) divisions. 5/7 Men and 4/6 Women were strength impaired as a result of paraplegia from a spinal cord injury, with 2/7 Men and 2/6 Women lower-limb deficient. All Quad players were male and 3/4 had tetraplegia from spinal cord injuries. The mean age of each division was 29 ± 9 yrs, 28 ± 6 yrs and 35 ± 6 yrs for Men, Women and Quad's respectively. The study was approved by the local ethical advisory committee. All players provided written informed consent prior to the competition.

Procedures

Physical and technical performance data were collected during the NEC Wheelchair Tennis Masters 2017. This singles competition includes the top 8 ranked players in the world for the Men's and Women's divisions and top 6 for the Quad division and is played on indoor hard courts. Physical measures of performance (distance, speed, acceleration and rotational metrics) were collected using a radio frequency based indoor tracking system and inertial measurement

units. Technical measures of performance (winners, errors, strokes per rally etc.) were collected via video analysis. A total of 22 matches were collected, resulting in 73 individual sets of data. All data were analysed with regards to i) the result of each set (win/loss) and ii) the margin of the set result (small ≤ 3 games differential; large > 3 games differential).

Measures and data processing

Activity profiles were measured using a radio-frequency, indoor tracking system (ITS) (Ubisense, Cambridge, U.K) sampling at ~ 16 Hz. A single small (40x40x10mm), lightweight (25g) tag was attached on/near the bar behind the backrest of each player. These tags communicate wirelessly with 6 sensors positioned around the perimeter of the court, as described previously (Rhodes, Mason, Perrat, Smith, & Goosey-Tolfrey, 2014). Data collection commenced at the beginning and terminated at the end of each set and was paused during stoppages (e.g. between games and injury timeouts). During each set the total distance covered, mean speed, peak speed, time spent performing low (LSA $< 1.0 \text{ m}\cdot\text{s}^{-1}$), moderate (MSA $1.0 - 2.0 \text{ m}\cdot\text{s}^{-1}$) and high (HSA $> 2.0 \text{ m}\cdot\text{s}^{-1}$) speed activity and the relative number of HSA ($\text{n}\cdot\text{min}^{-1}$) performed was analysed. Players' wheelchairs were also equipped with three inertial measurement units (IMU) (Shimmer3, Shimmer Sensing, Ireland) sampling at 199.8 Hz. One IMU was attached to the camber bar of the wheelchair with the remaining two fixed around the axis of each wheel. All IMU data were filtered using a 2nd order low-pass Butterworth filter (25 Hz cut-off frequency), as described previously (van der Slikke, Berger, Bregman, & Veeger, 2016), to quantify the mean acceleration, rotational velocity and rotational acceleration. Turning direction was also quantified by the IMU, with a turn defined as a 160° change in either the direction of the racket (R) or non-racket (NR) hand. To obtain a measure of internal load, players were asked to report an overall rating of perceived exertion (RPE) for each set

using the CR-10 scale within 30 minutes after the match (Borg, 1998). This was then multiplied by the set duration (minutes) to give a session RPE (sRPE) value (Foster et al., 2001).

All matches were filmed for live television and the footage was used for analysis of the technical activities performed. Video footage was analysed using Dartfish TeamPro Data 6.0 (Fribourg, Switzerland) by two analysts familiar with the software and tennis. Descriptive technical activities including the number of points per set, shots per set, strokes per rally, how many bounces shots were hit off and the type of stroke performed (forehand, backhand, volley etc.) were coded. Activities relating to how points were won were also coded and included the percentage of points won by the server and within the first two shots of the rally (serve or return), as well as the type of winner and errors made. Both analysts re-coded 4 sets worth of data from a random selection of matches so that the intra- and inter-observer reliability could be established. Intraclass correlation coefficients (ICCs) ≥ 0.94 (intra-observer) ≥ 0.64 (inter-observer) were observed across all variables which was deemed acceptable based on similar previous analyses (Mason, Altmann, & Goosey-Tolfrey, 2018; Mason, van der Slikke, Hutchinson, Berger, & Goosey-Tolfrey, 2018). The type of groundstroke performed (topspin, flat or slice) was also coded, however the inter-observer ICCs for these ranged between 0.34 – 0.41 for forehands and 0.13 – 0.28 for backhands. The agreement between observers was deemed too low and subsequently the type of groundstroke was excluded from further analysis.

Statistical analyses

Data were presented as means $\pm$ standard deviation (SD). All statistical analyses were conducted using the Statistical Package for the Social Sciences (version 23.0: SPSS, Chicago, IL). Shapiro-Wilk tests confirmed that data were normally distributed. Levene's tests confirmed that variances in data were homogenous. A multivariate analysis of variance

(MANOVA) was performed for all physical and technical measures of performance. Main effects were calculated for division (Men, Women, Quad), result (win / lose) and score margin (small / large) as were the interactions between each. Statistical significance was accepted as $P < 0.05$. Post-hoc tests with Bonferroni's correction were applied to determine where significant differences existed between divisions. Effect size (Cohen's d) was also calculated to determine the magnitude of any differences in performance (Cohen, 1988) and were categorised as trivial (<0.2), small ($0.2 - 0.6$), moderate ($0.6 - 1.2$), large ($1.2 - 2.0$) and very large (>2.0) according to previous guidelines (Batterham & Hopkins, 2006). The range within which the true effect size existed was determined using 95% confidence intervals (95% CI).

RESULTS

Activity profiles were higher during Men's matches in relation to both Women's and Quad's matches and during Women's matches in relation to Quad's matches for most parameters (Table 1). sRPE was the only physical parameter not to differ significantly between divisions. Fewer statistically significant differences between divisions were revealed for technical measures of performance, with the majority occurring between Men and Women as well as Men and Quad divisions (Table 2). Men hit fewer shots off 2 bounces, hit a lower percentage of forehands, won a higher percentage of points on serve and hit more volley winners than Women ($P \leq 0.035$) and Quad's ($P \leq 0.022$). Fewer strokes per rally were observed during Quad matches compared to Men's ($P = 0.027$) and Women's ($P = 0.004$) matches. No further statistically significant differences in technical performance were observed between Women and Quad divisions (Table 2)

INSERT TABLE 1&2 HERE

A minimal number of physical and technical measures of performance were significantly affected by set result (Figure 1). Players performed more HSA and made more errors during losing sets, with more winners and points won by the server during winning sets. However, the effect sizes of these differences were only small (Figure 1). The only significant interactions between result and division were revealed for peak speed and the percentage of points won by the server (Figure 2). Differences in peak speed during winning and losing sets were trivial for Men (3.85 ± 0.37 vs. 3.83 ± 0.26 m·s⁻¹ respectively). Whereas small decreases were revealed for Women (3.32 ± 0.27 vs. 3.44 ± 0.24 m·s⁻¹ respectively) and moderate increases in peak speed were observed for Quad's (3.32 ± 0.34 vs. 3.02 ± 0.16 m·s⁻¹ respectively) during losing sets compared to winning sets. Women and Quad's won a higher percentage of points on serve during winning sets. Alternatively, this percentage was higher for Men during losing sets (Figure 2).

INSERT FIGURE 1&2 HERE

Score margin had a larger bearing on performance measures than set result based on the magnitude of effect sizes observed (Figure 3). Activity profiles increased by a moderate to large effect during sets with a small score margin. The only technical parameters affected by score margin were the points won by the server and the strokes per rally, which both increased during sets with a small score margin, with a small to moderate effect (Figure 3). No significant interactions existed between score margin and division. However, several significant interactions existed between score margin and set result for physical aspects of performance (Figure 4). Mean speed, LSA and HSA were not significantly different between losing sets, regardless of margin. Whereas mean speed and HSA were lower and LSA greater when winning by a large margin. Rotational velocity and rotational acceleration were not

significantly different during winning sets, regardless of margin, yet both decreased during losing sets with a large margin (Figure 4).

INSERT FIGURE 3&4 HERE

DISCUSSION

The current study was the first to investigate the physical and technical demands of elite WT players and to differentiate the findings across the three different divisions. It was also the first to consider the impact that set result and score margin can have on these demands during singles competition. Large differences in physical rather than technical performance existed between different divisions. Technical measures of performance were affected by set result to a greater extent than physical performance. The opposite was true regarding score margin, whereby activity profiles were elevated during sets with a small score margin, whereas little effect on technical performance was observed. These findings provide coaches and practitioners with pertinent information about the physical and technical demands placed upon WT players, how these demands differ according to situational factors and what is most critical to successful performance. This information should assist coaches with the planning of both physical and technical preparation strategies.

As anticipated, the physical demands of WT differed considerably amongst the divisions. Activity profiles were elevated during the Open divisions (Men and Women) in relation to players from the Quad division. The fact that Quad players covered less distance at lower speeds is likely attributed to the reduction in physiological capacity and muscular strength experienced by these individuals (Janssen, Dallmeijer, Veeger, & van der Woude, 2002). Activity profiles were also elevated during Men's matches compared to Women's

matches. In particular, Men's matches were played at a higher mean speed with more HSA performed throughout. Although anthropometric data, such as height, body mass and limb length were not available, it is likely that these factors along with strength were all superior in male WT players as has been reported previously between genders (Cavedon, Zancanaro, & Milanese, 2018) and would most likely account for the elevated activity profiles observed. One interesting finding that was not anticipated was that the rotational velocity during turning was actually greater during Women's matches compared to Men's. Since a similar level of impairment can be expected between these two divisions, based on the range of health conditions and impairments reported, it is likely that a lower body mass possessed by female players may account for their greater rotational velocity. Rotational measures of performance have not been objectively measured during competition, despite its perceived importance to WT players (Mason, Porcellato, van der Woude, & Goosey-Tolfrey, 2010), which demonstrates the value of including IMUs alongside the global measures of external load provided by the ITS (Mason et al., 2018; van der Slikke, Berger, & Goosey-Tolfrey, 2017).

Despite the differences in activity profiles, internal workload did not differ significantly across the divisions. It has already been determined that gender impacts on muscular strength (Cavedon et al., 2018), potentially leading to the greater peak speeds found. Furthermore, both gender (van der Woude, Bouten, Veeger, & Gwinn, 2002) and level of physical function (Leicht, Tolfrey, Lenton, Bishop, & Goosey-Tolfrey, 2013) impact on peak measures of aerobic capacity and could explain the differences in absolute activity profiles found between divisions. However, RPE has been shown to be similar at equal levels of relative exercise intensity, irrespective of level of physical function (Leicht, Bishop, & Goosey-Tolfrey, 2012). This therefore suggests that the relative physiological intensity of elite WT is similar between

divisions, and that differences in activity profiles are related to the absolute level of physical capacity.

Although a large number of differences in physical performance were observed between the divisions, fewer differences in technical performance were identified. Quad matches were typified by significantly shorter rallies than both Open divisions, whereas no differences were identified between the number of strokes per rally for Men's and Women's matches. This contrasts the only previous study that compared the technical differences of Men's and Women's WT, whereby rally duration and shots per rally were both found to be higher during female matches (Sanchez-Pay et al., 2017). It could be that a difference in expertise accounted for the differences observed between studies, since the participants investigated by Sanchez-Pay et al. (2017) were described as international, yet no information about world rankings was available. Alternatively, male and female players in the current study were all within the top-8 in the world rankings and at this level no differences in strokes per rally existed.

Although 2 bounces are permitted during WT, only 10% of groundstrokes were hit off 2 bounces in the Men's division, which was significantly lower than both the Women's and Quad divisions. The greater speed and acceleration possessed by male players may partly account for this, with players more capable of moving towards and hitting the ball before a second bounce. However, it is also likely that a greater ball speed is achieved in the Men's game. Given the superior strength previously referred to, it is likely that male players generate more speed in their groundstrokes, as has been observed during the able-bodied game (Reid, Morgan, & Whiteside, 2016), meaning that the ball will travel through to their opponent quicker, lessening the likelihood of a second bounce. Another interesting technical difference

identified between divisions was that more points were won by the server during Men's matches in relation to Women's and Quad matches, where the receiver won a larger portion of the points. This would seem to suggest that serving seems to be a disadvantage during Women's and Quad matches rather than an advantage like it is for the Men. Greater service speeds have previously been observed for men in able-bodied tennis (Reid et al., 2016), and could account for the current findings, as a faster serve effectively gives the receiver less time to hit an effective return. Whereas the reduced service speed expected during Women's and Quad matches, likely puts the receiver in an advantageous position since they can move their chairs prior to the serve being hit and then return the ball back to the server who has to get started from a virtually static position after serving. The assumption that serving may be a weakness for Women and Quad players is somewhat strengthened by the finding that Women hit more return winners than Men. These findings echo the trends observed during able-bodied tennis, whereby males win a higher percentage of points on serve than females and females return a higher percentage of serves (Reid et al., 2016).

The final notable difference between divisions for aspects of technical performance was the percentage of volleys performed and the number of volley winners observed. Although statistically insignificant, moderate effect sizes were revealed for Men to hit a higher percentage of volleys than Women and hit a significantly higher number of volley winners than Women and Quad's respectively. It appeared that a conscious effort was employed by male players to approach the net to win a point, which has been deemed an effective strategy during able-bodied tennis (Reid et al., 2016). This style of play might again have been made possible due to the greater activity profiles they elicit.

Despite all of the aforementioned differences in physical and technical performance between different divisions of WT, each division seemed to respond in a similar manner to the situational factors monitored, since few interactions existed between result and division and none existed between score margin and division. Independent of division, very few performance differences were observed during winning and losing sets. From a physical perspective, only the percentage and number of HSA increased during losing sets of tennis, which would suggest that losing players are not in control of the rally and hence more high-speed efforts are required to stay in the rallies. Alternatively, a larger number of technical parameters were found to differ between winning and losing sets. In general, these results all indicated that more winners were hit during winning sets and more errors made during losing sets, which is not surprising. However, these findings may also suggest that technical performance outweighs that of physical performance in WT players given their stronger association to the outcome of sets. This is in line with what has previously been observed within able-bodied tennis, where technical-tactical abilities are also said to dominate (Hoppe et al., 2016; Reid et al., 2016).

In contrast to the findings observed for set result, score margin seemed to have a greater impact on physical rather than technical measures of performance. Activity profiles were significantly elevated during sets where a small score margin existed. This increased external load was also supported by a higher internal load, with higher sRPE values reported by players when score margins were small. These findings could be partly due to the longer rallies observed during sets with a small score margin. No previous studies in tennis, either WT or able-bodied, have explored the impact of score margin on the physical and technical demands of match-play. The only previous study to explore this phenomenon did so in Australian

football, but still identified similar trends to the current study whereby small score margins had more of an effect on physical measures of performance than technical (Sullivan et al., 2014).

Independent of division, a number of significant interactions existed between set result and score margin for physical parameters of performance. Trivial to small differences were observed for the mean speed, time spent performing LSA and HSA and the number of HSA performed between small and large score margins during losing sets. However, the mean speed and HSA increased and the LSA decreased when winning by a small margin compared to a large margin. These observations and subsequent interpretations are consistent with the previous discussions regarding the main effects for result. For example, when winning with a large margin it is likely that the winning player is in control of the point so therefore requires fewer HSA to retrieve and return balls, thereby performing greater LSA. During winning sets, the degree of mean rotational velocity and acceleration were similar however when losing by a large margin, these were reduced by a small and moderate effect respectively. This would seem to emphasise the need for rapid rotational chair movements in WT since it was associated with both winning conditions. The fact it was also present during losing sets where the score margin was small would indicate that players movements and subsequent positioning was appropriate. The unfavourable result could have just been down to an unfavourable few points or poor shot selection at critical moments. Whereas the fact that rotational performance is reduced when losing by a large margin would suggest that players are not even getting into good positions frequently enough to be competitive during rallies. Subsequently rotational performance and the use of IMUs for quantifying this, would seem of value for tennis coaches and practitioners to develop their players.

In future, studies would be advised to monitor the type of groundstroke being performed to establish whether a certain type of stroke (topspin, flat or slice) is played more by a certain division or associated with greater success than other strokes. In particular the inverted or pronated backhand (topspin) has become a more common stroke over recent years and warrants investigation. However, the inter-observer reliability for the detection of such shots was too low for inclusion during the current study. Further studies of this nature would also be encouraged to synchronise the physical data with the technical data to provide coaches with more context about where on court certain activities are being performed. Larger sample sizes would have also been desirable for making comparisons across divisions, however this would have been difficult given the homogenous nature of the high-ranked WT players investigated.

CONCLUSIONS

The current study has revealed that differences in activity profiles exist between divisions in WT, although internal workload and technical performance are similar, as are the divisions responses to result and score margin. Independent of division, increased technical rather than physical performance seems paramount to set result. Although increased activity profiles are required during sets with small score margins. These findings have important implications for WT coaches and practitioners since the information presented demonstrates the physical and technical demands that players need to be prepared for according to division and the situational factors experienced during competition.

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Figure Legends:

Figure 1 Effect sizes ($\pm$ 95% CI) demonstrating the magnitude of statistically significant performance differences between winning and losing sets of WT. A negative effect size demonstrates performance measure was greater during losing sets and vice versa.

Figure 2 Significant interactions between result and division. Bars denote mean ($\pm$ SD). Effect sizes ($\pm$ 95% CI) signify magnitude of observed differences. A negative effect size demonstrates performance was greater during losing sets and vice versa.

Figure 3 Effect sizes ($\pm$ 95% CI) demonstrating the magnitude of statistically significant performance differences between sets of WT with a small and large score margin. All positive effect sizes indicate performance increased during sets with small score margins.

Figure 4 Performance measures where significant interactions between set result and score margin were identified. Bars denote mean ($\pm$ SD). Effect sizes ($\pm$ 95% CI) signify magnitude of observed differences. A negative effect size demonstrates performance was greater during sets with a large score margin and vice versa.

Winning Losing

a)

Distance

Mean speed

Peak speed

HSA

No. HSA

Session RPE

b)

Points won by server

Strokes per rally

Winning small

Winning large

Losing small

Losing large

Table 1 Differences in physical aspects of performance during sets of WT from different divisions. Values presented are means ($\pm$ SD)

	Main effect (division)	Men's	Women's	Quads	Effect sizes ($\pm$ 95% CI)		
					Men vs. Women	Men vs. Quad	Women vs. Quad
Duration (mm:ss)	0.016	39:18 (12:22)	34:01 (10:43)	28:50 (08:07)	0.3 (-0.3, 0.8)	1.1 (0.4, 1.8)*	0.9 (0.2, 1.6)*
Distance (m)	0.005	2220 (802)	1841 (648)	1275 (347)	0.5 (0.0, 1.1)	1.4 (0.7, 2.1)*	1.0 (0.3, 1.7)*
Mean speed (m·s ⁻¹)	<0.0005	1.20 (0.12)	1.10 (0.09)	1.01 (0.08)	0.9 (0.4, 1.5)*	1.8 (1.0, 2.5)*	1.0 (0.3, 1.7)*
Peak speed (m·s ⁻¹)	<0.0005	3.84 (0.31)	3.39 (0.25)	3.17 (0.30)	1.6 (1.0, 2.2)*	2.2 (1.4, 3.0)*	0.8 (0.1, 1.5)*
LSA (%)	0.002	44.3 (6.5)	44.4 (7.0)	53.3 (5.8)	0.0 (-0.5, 0.6)	1.4 (0.7, 2.2)*	1.4 (0.6, 2.1)*
MSA (%)	0.005	41.7 (4.9)	48.0 (7.4)	42.0 (5.2)	1.0 (0.4, 1.6)*	0.1 (-0.6, 0.7)	0.9 (0.2, 1.6)*
HSA (%)	<0.0005	14.1 (4.3)	7.6 (1.7)	4.8 (1.3)	2.0 (1.3, 2.6)*	2.6 (1.7, 3.5)*	1.8 (1.0, 2.6)*
No. HSA (n·min ⁻¹)	<0.0005	3.5 (0.7)	2.5 (0.7)	1.7 (0.4)	1.4 (0.8, 2.0)*	2.9 (2.0, 3.8)*	1.3 (0.6, 2.0)*
Mean acceleration (m·s ⁻²)	<0.0005	1.08 (0.18)	0.91 (0.15)	0.72 (0.08)	1.0 (0.4, 1.6)*	2.3 (1.5, 3.2)*	1.5 (0.7, 2.2)*
Turns – R (n·min ⁻¹)	<0.0005	5.6 (0.5)	6.2 (1.1)	4.9 (0.8)	0.7 (0.2, 1.3)	1.1 (0.4, 1.8)*	1.3 (0.6, 2.0)*
Turns – NR (n·min ⁻¹)	0.016	7.5 (0.7)	7.2 (1.0)	6.8 (0.6)	0.4 (-0.2, 0.9)	1.0 (0.4, 1.7)*	0.5 (-0.2, 1.1)
Rotational velocity (deg·s ⁻¹)	<0.0005	72.1 (5.0)	82.4 (8.9)	63.7 (4.9)	1.5 (0.8, 2.1)*	1.7 (0.9, 2.4)*	2.4 (1.6, 3.3)*
Rotational acceleration (deg·s ⁻²)	<0.0005	205 (28)	211 (29)	144 (31)	0.2 (-0.4, 0.7)	2.1 (1.3, 2.9)*	2.3 (1.4, 3.1)*
Session RPE (au)	0.175	136 (68)	101 (76)	94 (32)	0.5 (-0.1, 1.01)	0.7 (0.1, 1.4)	0.1 (-0.6, 0.8)

Turns – R: turns in the direction of the racket hand; Turns – NR: turns in the direction of the non-racket hand; au = arbitrary units; *significant difference between divisions

Table 2 Differences in technical aspects of performance during sets of WT across different divisions. Values presented are means ($\pm$ SD)

	Main effect (division)	Men's	Women's	Quads	Effect sizes ($\pm$ 95% CI)		
					Men vs. Women	Men vs. Quad	Women vs. Quad
Points per set (n)	0.076	66 (23)	54 (18)	52 (15)	0.6 (0.0, 1.2)	0.7 (0.0, 1.4)	0.2 (-0.5, 0.8)
1 st serve (%)	0.632	65.2 (10.2)	62.2 (10.3)	65.1 (10.9)	0.3 (-0.3, 0.9)	0.0 (-0.7, 0.7)	0.3 (-0.4, 0.9)
Strokes per rally (n)	0.005	3.2 (0.5)	3.1 (0.8)	2.5 (0.5)	0.2 (-0.4, 0.7)	1.2 (0.5, 1.9)*	0.7 (0.0, 1.4)*
Shots off 1 bounce (%)	0.138	85.7 (6.8)	82.1 (7.6)	81.5 (6.2)	0.5 (-0.1, 1.1)	0.6 (0.0, 1.3)	0.1 (-0.6, 0.8)
Shots off 2 bounces (%)	0.026	10.0 (5.5)	15.7 (7.9)	16.1 (6.9)	0.8 (0.2, 1.4)*	1.0 (0.3, 1.7)*	0.1 (-0.6, 0.7)
Forehands (%)	0.009	43.6 (6.9)	49.6 (7.8)	51.0 (11.7)	0.8 (0.2, 1.4)*	0.8 (0.1, 1.5)*	0.1 (-0.5, 0.8)
Backhands (%)	0.040	51.8 (7.7)	48.0 (7.6)	45.0 (8.9)	0.5 (-0.1, 1.1)	0.8 (0.1, 1.5)*	0.4 (-0.3, 1.0)
Volleys (%)	0.237	4.6 (3.8)	2.4 (1.9)	3.6 (3.5)	0.7 (0.1, 1.3)	0.3 (-0.4, 0.9)	0.5 (-0.2, 1.1)
Points won by server (%)	0.005	56.0 (10.6)	44.0 (12.4)	44.6 (13.6)	1.0 (0.4, 1.7)*	1.0 (0.3, 1.7)*	0.0 (-0.7, 0.8)
Points won within 2 shots (%)	0.106	25.5 (14.8)	36.2 (18.5)	32.8 (16.0)	0.6 (0.1, 1.2)	0.5 (-0.2, 1.2)	0.2 (-0.5, 0.9)
Winners	0.100	0.29 (0.09)	0.33 (0.12)	0.26 (0.10)	0.4 (-0.2, 1.0)	0.3 (-0.3, 1.0)	0.6 (-0.1, 1.3)
Errors	0.196	0.21 (0.08)	0.19 (0.04)	0.22 (0.05)	0.3 (-0.3, 0.9)	0.1 (-0.5, 0.8)	0.7 (0.0, 1.4)
Groundstroke winners	0.085	0.20 (0.06)	0.23 (0.09)	0.18 (0.07)	0.4 (-0.2, 1.0)	0.3 (-0.3, 1.0)	0.6 (-0.1, 1.3)
Return winners	0.013	0.09 (0.07)	0.18 (0.11)	0.11 (0.09)	1.0 (0.4, 1.6)*	0.3 (-0.4, 0.9)	0.7 (0.0, 1.4)
Forehand winners (%)	0.468	61.8 (14.9)	60.1 (18.6)	66.3 (16.4)	0.1 (-0.5, 0.7)	0.3 (-0.4, 1.0)	0.3 (-0.3, 1.0)
Service winners	0.143	0.03 (0.03)	0.01 (0.02)	0.05 (0.07)	0.8 (0.2, 1.4)	0.4 (-0.3, 1.1)	0.9 (0.2, 1.6)
Volley winners	0.003	0.04 (0.03)	0.01 (0.02)	0.01 (0.01)	1.2 (0.5, 1.8)*	1.2 (0.5, 1.9)*	0.0 (-0.7, 0.7)
Winners off 1 bounce (%)	0.314	91.2 (8.4)	91.8 (11.0)	87.9 (9.0)	0.1 (-0.5, 0.6)	0.4 (-0.3, 1.0)	0.4 (-0.3, 1.1)
Winners off 2 bounces (%)	0.049	4.9 (7.0)	7.6 (10.3)	12.2 (9.0)	0.3 (-0.3, 0.9)	0.9 (0.2, 1.6)*	0.5 (-0.2, 1.1)
Groundstroke errors	0.561	0.27 (0.09)	0.24 (0.06)	0.25 (0.08)	0.4 (-0.2, 1.0)	0.2 (-0.4, 0.9)	0.1 (-0.5, 0.8)
Return errors	0.447	0.15 (0.08)	0.18 (0.09)	0.16 (0.12)	0.4 (-0.2, 0.9)	0.1 (-0.6, 0.8)	0.2 (-0.5, 0.9)
Forehand errors (%)	0.731	45.9 (18.3)	48.0 (16.6)	49.9 (16.1)	0.1 (-0.5, 0.7)	0.2 (-0.4, 0.9)	0.1 (-0.6, 0.8)
Service errors	0.062	0.06 (0.06)	0.07 (0.05)	0.10 (0.06)	0.2 (-0.4, 0.8)	0.7 (0, 1.3)	0.6 (-0.1, 1.2)
Unforced errors (%)	0.390	68.8 (14.1)	75.4 (12.8)	68.4 (21.6)	0.5 (-0.1, 1.1)	0 (-0.6, 0.7)	0.4 (-0.3, 1.1)

Nb – winners and errors are reported as a ratio to the number of points played; *significant difference between divisions