Adapted Physical Activity Quarterly, (Ahead of Print)
https://doi.org/10.1123/apaq.2017-0117

Human Kinetics
ORIGINAL RESEARCH

The Effect of Prior Tennis Experience on Wheelchair Tennis Players' Visual Search

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The purpose of this study was to examine whether prior biped tennis playing experience results in different visual search strategies compared with no prior biped playing experience. A total of 32 wheelchair (WC) tennis players, 17 males and 15 females, ranked between 1 and 16 on the International Tennis Federation rankings participated in this study. Half the players had prior experience playing tennis as a biped player, and half had no prior experience in biped tennis. The athletes viewed 18 different serves from an expert WC player while their gaze was monitored using eye tracking. Results revealed significant differences between the groups in fixation duration and number of fixations. Differences were also found in fixation locations and durations across biomechanical phases of the serve. The WC only players had more fixations for shorter periods than did WC with biped players in the ritual phase. In the preparatory and execution phases, however, the WC only players had fewer fixations for longer duration than the WC with biped players. Results are discussed in terms of long-term memory structures, learning, and considerations when coaching and training WC tennis players.

Keywords: attentional control, eye tracking, fixations, open skill, visual behavior

Visual search (VS) is knowing where to look and what to look for while playing sport. VS influences many areas of performance, such as anticipation time and accuracy (Starkes & Ericsson, 2003), decision-making abilities (Millazzo, Farrow, & Fournier, 2016), movement time (Williams, Davids, & Williams, 1999), cognition (Williams & Grant, 1999), and long-term memory (Reina et al., 2004).

Past researchers have found that experts compared with novices have fewer fixations of longer duration (e.g., Perez, Mendez, Manzano, & Collado, 2013; Piras, Pierantozzi, & Squatrito, 2014), which reduce their processing time, resulting in an increased response accuracy (Mann, Williams, Ward, & Janelle, 2007) and reduced decision-making time and accuracy (Piras et al., 2014). In addition, experts look at biomechanical cues that provide predictive information.

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This paper is dedicated to the memory of Carma Lee Lewallen.

These VS patterns are not random, but rather based on deliberate perceptual-cognitive strategies (Bard & Fleury, 1981).

Effective VS enables the expert to analyze a scene more efficiently and extract information, which helps predict the correct response. According to Reina et al. (2004) and Williams and Grant (1999), from a cognitive point of view, VS strategies determine specific task knowledge structures situated in long-term memory. Through learning and practice the most important areas of the scene can be visually processed. Therefore, VS strategy is controlled by knowledge and developed through training, competing, and observation (Reina et al., 2004).

VS patterns have been seen to be domain specific (Chen et al., 2017). For instance, according to Chen et al., Taekwondo, which emphasizes kicking, might require faster perceptual processing to compensate for longer latencies to initiate lower-limb movements and to give rapid visual feedback for dynamic postural control, whereas karate, which emphasizes both striking with the hands and kicking, might require exceptional eye–hand coordination and fast perceptual processing. Therefore, because you are good at one task does not mean you will have an appropriate VS pattern for other tasks.

Experts in racquet sports, such as badminton, tennis, and squash, have some broad similarities in VS patterns (Cauraugh & Janelle, 2002). For instance, arm, racquet, and ball toss regions have been shown to be important visual cues that affect anticipation (Abernathy, 1988; Moreno, Oña, & Martínez, 2002). Furthermore, experts use advanced (preflight) cues that occur earlier in the stroke than novices; this allows the expert greater speed and accuracy in predicting the type and location of the stroke (Reina, Moreno, & Sanz, 2007).

Expert biped tennis players, when returning serve, look first at the general body position (GBP) and nondominant arm (NDA; or free arm that tosses the ball) during the ritual phase, which proceeds the initiation of the serve and consists of ball bounces and foot positioning (Hunfalvay, 2004). They then shift their gaze to the NDA (Goulet, Bard, & Fleury, 1989) during the preparatory phase, which begins at the elevation of the arm holding the ball and ends at the apex of the ball trajectory. During the execution phase, which begins at the servers' knee extension and ends at the ball/racquet contact, the longest fixation durations were on the arm, racquet, and shoulder regions (Goulet et al., 1989; Hunfalvay, 2004; Murray & Hunfalvay, 2017; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; Singer et al., 1998; Tenenbaum, Levy-Kolker, Sade, Liebermann, & Lidor, 1996). During the finishing phase, which begins after contact and continues throughout the flight of the ball, gaze was then located on or in front of the ball (Hunfalvay, 2004; Murray & Hunfalvay, 2017; Singer et al., 1998).

According to a research study by Reina et al. (2007), expert wheelchair (WC) tennis players spent the most time in the ritual phase on the GBP (upper) and then on the ball in the preparatory, execution, and finishing phases. They spent less time on the contact point, where the racquet and ball meet. Reina et al. postulated that the higher number of visual fixations on the ball could be due to the WC server grabbing the rim of the WC with the free arm to gain stability. In the same study, Reina et al. compared wheelers' VS patterns when viewing biped servers and found that the wheelers viewed the NDA of the biped server and not the ball during the preparatory phase. These results show differing VS patterns when wheelers view biped servers versus other wheelers. Results may be due to differences between WC and biped tennis and would be consistent with past findings suggesting VS patterns are domain specific (Chen et al., 2017).

WC tennis players use the same rules (although have options to allow the ball to bounce twice) and have the same standardized courts, same surfaces, and same equipment as bipeds. However, they vary in their visual perspective of their opponent. As a biped player, the person looks over and above the net; by contrast, the WC tennis player looks through the net. The visual angle is therefore different. Furthermore, while the biped players use their legs for movement on the court, the WC players use the same body part to move and to swing at the ball (that is their hands).

Returning a tennis serve is a temporally constrained situation that demands all players extract the most valuable pieces of information and use this information quickly to anticipate the serve (direction, spin, and speed; Shim, Miller, & Lutz, 2005). In the case of an expert wheeler's serve (an average of 40–45 m/s), the player has only 500–600 ms to make decisions about how to respond (Abernathy, 1991). In the case of expert biped tennis, serves can reach 67 m/s, allowing the player much less time to return. Reina et al. (2007) suggested that differences in VS patterns between viewing biped and wheelers servers from the perspective of a wheeler may be due to the time constraints that affect wheelers differently than biped players when returning serve. Specifically, Reina et al. (2007) state that wheelers are "quicker in pursuing the ball's path because wheelchair opponents' servers are slower than ambulatory performers serves." Therefore, this provides the wheeler more time to respond to the flight of the ball than biped servers. In summary, the differences in speed, visual angle, and use of hands to move the WC may contribute to differences in WC VS skills compared with bipeds.

To date, all research conducted on wheelers has been done with wheelers who began playing tennis from a WC (Reina et al., 2004, 2007; Reina, Moreno, Sanz, Damas, & Luis, 2010) and had no experience in playing tennis as a biped. Furthermore, there are no findings to date that have compared expert WC tennis players who have previous biped experience (WC with biped [WCB]) with those who do not have biped experience (WC only [WCO]). In the past research, some authors have stated that previous experience underlies VS mechanisms and subsequent decision-making processes, as indicated by expert/novice differences in fixation location and durations (Jackson & Mogan, 2007). VS uses task-specific knowledge based on long-term memory that is controlled and developed through training (Williams & Grant, 1999). Therefore, transitioning from playing as a biped to a wheeler leads to the following question: Does the new wheeler have VS strategies that mirror the biped

or have they transitioned to a wheeler strategy? The answer to this question is important in several ways, including time to adjust a VS strategy as well as possible training and coaching methods. Therefore, the purpose of this study was to determine whether prior biped tennis playing experience resulted in different VS strategies (number of fixations, fixation durations, and fixation locations) compared with no prior biped experience for wheelers.

Methods

Participants

A total of 32 WC tennis players (aged 19–41, $M = 28.38$, $SD = 8.77$; 17 males and 15 females) participated in the experiment. Players' highest ranking between August 31, 2002, and August 31, 2003, was between 1 and 16 on the International Tennis Federation tour.

WCO participants ($n = 16$) had played tennis from a WC for an average of 10.19 ($SD = 6.02$) years. The WCB participants ($n = 16$) had played tennis (biped and WC tennis) for an average of 11.63 ($SD = 6.17$) years; they played biped tennis for an average of 7.69 ($SD = 5.64$) years and WC tennis for an average of 4.44 ($SD = 1.93$) years. This study was approved by the institutional review board for the behavioral sciences at the University of Virginia (2003-0126-00).

Task and Measures

Test Film. The current world's number-one-ranked male (International Tennis Federation, aged 30, and 10 years of tennis playing experience from a WC) at the time of data collection was the model in this study. The model was filmed from a "front-on" perspective using a digital video camera (DCR-TRV 19; Sony, Oradell, NJ). The video camera was positioned 91.44 cm behind the intersection of the sideline and baseline at the height of 120.65 cm, based on the model's height while seated in a WC tennis chair. The model performed 18 serves, nine on each side of the court. Serves were hit in three directions (wide, at the body, or down the center) and with three types of spin (flat, slice, and topspin).

The videotape was edited using the Pinnacle Studio version 7 (Pinnacle Systems, Inc., Ottawa, ON; https://www.pinnaclesys.com/en/) editing system. The naturally occurring sounds associated with each serve were included in the videotape. The serves were shown in real time, and the total duration of the video was 44.47 s, including a 2-s gray screen presentation between each of the 18 serves. The average duration of each serve was 2,470 ms ($SD = 0.39$), and the serves were presented in random order.

Each serve was recorded from when the server moved up to the baseline to begin the service motion and terminated when the ball crossed the net. Each serve included four phases of the WC tennis serve: the first phase, the ritual phase, precedes the initiation of the serve consisting of ball bounces and chair positioning ($M = 1{,}130$ ms, $SD = 0.14$). The second phase, the preparatory phase, begins at the elevation of the arm holding the ball and ends at the apex of the toss ($M = 630$ ms, $SD = 0.18$). The third phase, the execution phase, begins at the upward extension of the body and ends at the point of contact between the racquet and ball ($M = 330$ ms,

$SD = 0.12$). The fourth phase, the finishing phase, starts immediately after ball–racquet contact and ends as the ball crosses the net, at which time the video was cut ($M = 410$ ms, $SD = 0.13$).

The Eye-Gaze Response Interface Computer Aid. An Eye-Gaze Response Interface Computer Aid (2003, model 000-0-103; http://www.eyegaze.com/) system was used to collect VS data. System parameters were the same as in Murray and Hunfalvay (2017). System accuracy and precision were ±0.5° of visual angle with a data sampling rate of 60 frames per second. Eye calibration was automatic using a 1-point eye calibration screen and then a 16-point screen calibration. The videos were displayed on the Eye-Gaze Response Interface Computer Aid system, which utilized a 21-in. screen at 60 Hz with a spatial resolution of 0.5°. Participants were positioned 90 cm away using 18.72° × 24.28° field of view.

Procedure

Testing was conducted at various locations and times during professional tennis tournaments. Upon arrival for testing, participants completed both an informed consent form and a demographic questionnaire. Participants' eye gaze was calibrated, and then they were read a statement of instructions where they were asked to watch the serve and "imagine you are on the tennis court playing this person in a competitive match situation, such as at this tournament here in (location) . . . you are about to return serve during the match . . . think about and imagine trying to return the serve as effectively as possible making it difficult for the server to return."

If the participants had no questions, they watched three serves presented in random order to familiarize themselves with the video presentation, and if there were no further questions, participants were again checked for calibration and watched each of the 18 testing videos in their entirety. During this viewing, their eye-gaze responses were monitored in terms of number of fixations, fixation durations, and pursuit tracking during temporal segments and at specific locations throughout the presentation of the serve.

Data Reduction

VS variables included the number of fixations and fixation durations. A fixation is defined as a period of at least 100 ms during which all gaze points are recorded within 3° of visual angle of each other. The number of fixations was summed for each serve and then averaged across the 18 serves. Pursuit tracking of the ball was also recorded. The number of fixations and fixation durations were calculated for each temporal phase (ritual, preparatory/execution, and finishing). Fixation locations were also examined and are referred to as "areas of interest" (AOIs). Fixation durations were averaged for each AOI and then averaged across serve type.

Five locations (AOIs) that have been determined to be important in past research were created (Goulet et al., 1989; Singer et al., 1998; Tenenbaum et al., 1996). All AOIs, except AOI 5 (predictive AOI), were present for the entire duration of the service motion and were similar to Reina et al. (2007). The GBP, referred to as AOI 1, included the torso, head, legs, and WC. The NDA, referred to as AOI 2, was created around the nondominant tossing arm of the model server.

The arm, racquet, and shoulder region of the server's dominant arm was referred to as AOI 3. AOI 4 was created around when the ball and racquet meet. AOI 5, the predictive AOI, was present from when the model first appeared on the screen and until the NDA was raised to waist height during the preparatory phase. It was located along the tossing path of the arm and ball flight during the tossing phase and was designed to capture eye movements that occurred prior to the toss.

Data Analysis

To test the hypotheses of interest, a one-way analysis of variance (ANOVA) was used to analyze group differences (WCB and WCO tennis compared with WC tennis only) for average total fixation duration. In addition, two 2 (group) × 4 (phase) ANOVAs were conducted by examining fixation durations and number of fixations for the ritual, preparatory, execution, and finishing phases. Effect size was evaluated through partial eta squared. A multiple regression analysis was conducted to evaluate how well the fixation duration locations predicted time playing tennis. Alpha was set at $p < .05$ as the critical level of significance for all comparisons. When necessary, violations of the sphericity assumption were corrected using Greenhouse–Geisser adjustments of the degrees of freedom.

Results

For the initial analysis, we included gender as a factor; however, this was nonsignificant. We then examined rank between groups, which was also nonsignificant ($p = .152$, $\eta_p^2 = .043$). Thus, all comparisons are made by group (WCB compared with WCO).

A one-way ANOVA for group comparing average total fixation duration produced a significant effect, $F(2, 30) = 362.08$, $p < .001$, $\eta_p^2 = .923$. The WCB players overall had shorter fixation durations ($M = 499.68$, $SD = 10.75$) than WCO players ($M = 599.25$, $SD = 17.95$). Furthermore, the 2 (group) × 4 (phase) ANOVA for duration produced a significant main effect for group, $F(2, 30) = 27.98$, $p < .001$, $\eta_p^2 = .483$, and for phase, $F(2, 30) = 155.08$, $p < .001$, $\eta_p^2 = .838$ (see Figure 1). In addition and more importantly, there was also a significant interaction effect, $F(2, 30) = 40.82$, $p < .001$, $\eta_p^2 = .576$. The main effects and interactions both demonstrated large effect sizes (Cohen, Cohen, West, & Aiken, 2003). The simple effects analysis revealed that WCB players fixated significantly longer during the ritual phase, whereas WCO players had longer fixation durations in the preparatory and execution phases of the serve (see Table 1).

The 2 (group) × 4 (phase) ANOVA for the number of fixations revealed a significant main effect for group, $F(2, 30) = 32.76$, $p < .001$, $\eta_p^2 = .522$, and for phase, $F(2, 30) = 297.62$, $p < .001$, $\eta_p^2 = .908$, and a significant interaction effect, $F(2, 30) = 90.243$, $p < .001$, $\eta_p^2 = .751$ (see Figure 2). As for the other analyses, the main effects and interactions both produced large effect sizes. The simple effects analysis for the number of fixations revealed that WCB players had significantly fewer fixations during the ritual phase, whereas WCO players had fewer fixations in the preparatory and execution phases of the serve (see Table 2). There was no difference for the finishing phase.

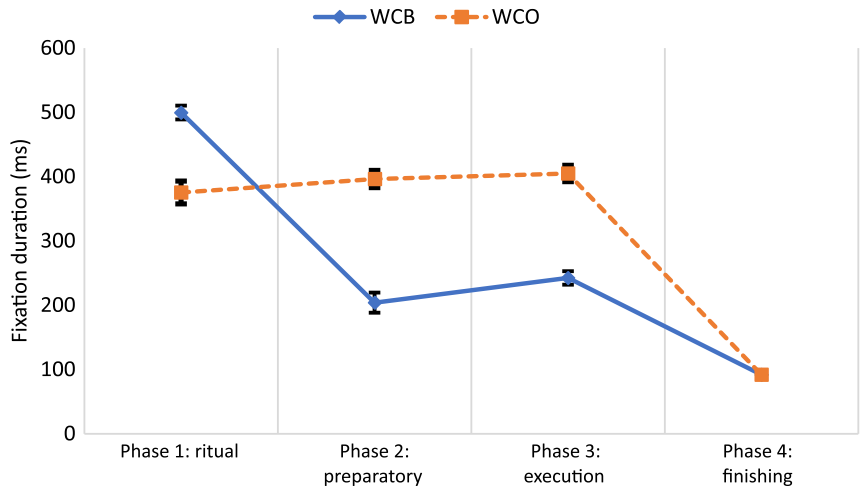

Figure 1 — Average fixation duration by phase for WCB and WCO players. WCB = wheelchair with biped; WCO = wheelchair only.

Table 1 Average Fixation Duration (*SD*) by Group and Phase

Phase	WCB	WCO
Phase 1: ritual	499.68 (10.75)*	375.31 (46.31)*
Phase 2: preparatory	203.93 (15.65)*	396.25 (13.99)*
Phase 3: execution	242.37 (10.56)*	404.87 (12.72)*
Phase 4: finishing	91.68 (3.55)	91.87 (3.91)

Note. WCB = wheelchair with biped; WCO = wheelchair only.
*$p < .001$.

It was immediately apparent that the majority of fixations during the ritual phase were on the GDP and NDA for the WCB and WCO players, respectively (see Table 3). Subsequent phases also revealed that a majority of fixations were located within a specific region at biomechanical phases. We conducted a qualitative assessment to examine the dominant areas for each group for each fixation location. Following this assessment, we only included the data within those AOIs for further analysis.

Regression Analysis

The linear combination of fixation duration location indices was not significantly related to time playing tennis, $R^2 = .01$, $F(4, 27) = 0.396$, $p = .81$, with only approximately 1% of the variance of the time playing tennis accounting for the variance in fixation duration/location indices. Therefore, it was hypothesized that the fixation strategies of WCO players are different than WCB players.

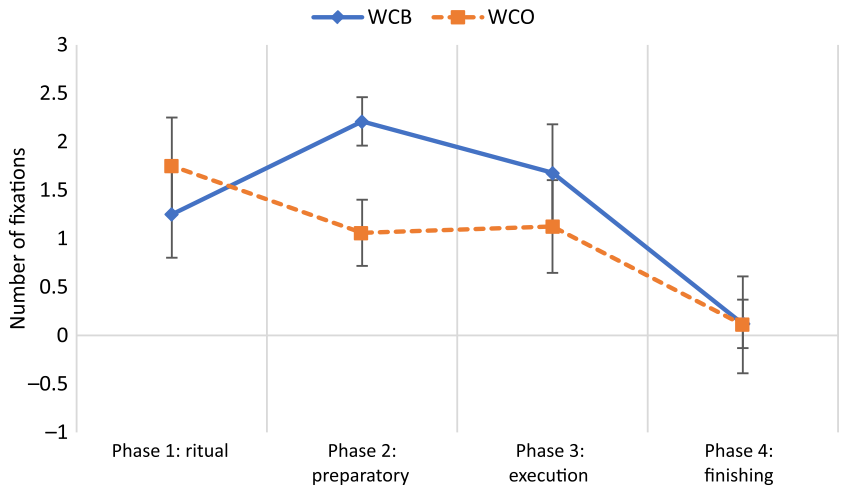

Figure 2 — Number of fixations per group separated by phase. WCB = wheelchair with biped; WCO = wheelchair only.

Table 2 Number of Fixations (*SD*) by Group and Phase

Phase	WCB	WCO
Phase 1: ritual	1.25 (0.35)*	1.75 (0.44)*
Phase 2: preparatory	2.21 (0.34)*	1.06 (0.25)*
Phase 3: execution	1.68 (0.47)*	1.125 (0.51)*
Phase 4: finishing	0.12 (0.49)	0.11 (0.39)

Note. WCB = wheelchair with biped; WCO = wheelchair only.
*$p < .001$.

Table 3 Fixation Location at Each Biomechanical Phase for the WCB Group and the WCO Group

Group	Ritual phase	Preparatory phase	Execution phase	Finishing phase
WCB	GBP	NDA	Contact	Ball
WCO	NDA	Contact	Contact	Ball

Note. WCB = wheelchair with biped; WCO = wheelchair only; GBP = general body position; NDA = nondominant arm.

We then performed a secondary descriptive analysis and examined the fixation location strategy of WCB players compared with WCO players. During the ritual phase, the primary location for WCB players was GBP, whereas WCO players fixated on the NDA and predictive toss path. During the preparatory phase, the

WCB players shifted to NDA and predictive toss path, whereas the WCO players shifted to the contact point and remained there until ball contact during the execution phase. However, the WCB players did not shift to ball contact point until the execution stage, and both groups fixated on the ball during the finishing phase.

Discussion

The purpose of this study was to examine the VS patterns of WC tennis players. We compared "wheelers" who had past biped playing experience with wheelers who had no past biped playing experience. Results revealed that past playing experience may influence VS patterns. The WCB group has significantly different VS patterns than the WCO group. WCB players fixated significantly longer during the ritual phase, whereas WCO players had longer fixation durations in the preparatory and execution phases of the serve. WCB players had significantly fewer fixations during the ritual phase, whereas WCO players had fewer fixations in the preparatory and execution phases of the serve. The WCO group had overall fewer fixations for longer duration than the WCB group. Furthermore, the groups differed in the locations of their fixations at the biomechanical phases of the serve (see Table 3).

The WCB group had past playing experience as biped tennis players. Their VS patterns are similar to biped players VS patterns (Goulet et al., 1989; Hunfalvay, 2004; Murray & Hunfalvay, 2017; Singer et al., 1996, 1998; Tenenbaum et al., 1996). Expert biped tennis players look at the GBP during the ritual phase, then the NDA in the preparatory phase, then the contact point during execution, and follow the ball during the finishing phase. These results suggest that past playing experience may be reflected in VS patterns for this group.

The WCO group only played tennis from a WC and had no prior experience playing biped tennis. Their VS patterns were significantly different than those with past biped experience. These results are consistent with Reina et al. (2007) in that their results showed different VS patterns between wheelers who viewed other wheelers serving and those who viewed biped servers. These results are also consistent with research by Murray and Janelle (2003) who found that the VS process is likely context dependent and influenced by the task, the skill, and the environmental conditions.

The WCO players had more fixations for shorter periods than did WCB players in the ritual phase. Past research has shown that longer durations with fewer fixations are consistent with individuals who are more experienced at the task (Starkes & Ericsson, 2003). In the preparatory and execution phases, the WCO players had fewer fixations for longer duration than the WCB players. Shorter durations and more fixations have been associated with less experience (Starkes & Ericsson, 2003). However, these athletes are all world class, highly ranked tennis players. One possible explanation could be the biomechanical differences associated with the serve from a biped to a WC. As the WCO players had a more "expert" VS pattern during this phase (longer durations and fewer fixations), it may be due to a domain-specific knowledge required in WC tennis. The results may also be due to the specific model used for the study. Future research should consider several models to further generalize results. Another explanation may be the trade-off that

occurs in the efficiency of the VS pattern between fixations and scanning behavior indicated by saccades and smooth pursuit eye movements. Longer fixations increase fidelity from each location at the expense of exploring fewer locations. If fixations are shorter, then additional locations can be explored (Najemnik & Geisler, 2009). Some research has shown that adopting different cognitive strategies (passive vs. active) influences VS behavior of participants at the same skill level of a task (Watson, Brennan, Kingstone, & Enns, 2010).

Furthermore, some research suggests that execution and finishing phases may be key service components that WC players must focus on (Reina et al., 2007). It is possible that the differences in the ritual and preparatory phases may therefore be of little importance in terms of ability to return the serve (from a VS perspective), although these differences are interesting from the lasting effects of previous biped tennis experience. In other words, differences exist as stored in memory; however, all players are WC tennis experts, therefore the differences are not necessarily affecting the most important components of the serve, which have been adapted to comply with new task (WC serve) constraints.

This study differs from past research in that the scan path adopted by the WCO was different than what was found by Reina et al. (2007; see Table 4). Participants in Reina et al.'s study also had no past playing experience as a biped tennis player. The WCO players in this study looked at the contact point for longer period than the ball in the preparatory and execution phases compared with Reina et al.'s study. It is possible that these differences are negligible as the ball and contact point are together the areas most viewed in these phases. A limitation in Reina et al.'s study is the low number ($N = 5$) of expert wheelers. However, additional research with highly skilled wheelers could assist in clarifying which location of gaze is used the most in preparatory and execution phases.

As all participants were highly experienced, with similar years of tennis playing experience in a WC, the results cannot be related to age, years playing, or level of expertise as a WC tennis player. As VS patterns are domain specific, it seems that participants in the WCO group developed different VS patterns than those who had no prior biped tennis experience. As VS patterns are based on long-term memory, it may be that the WC server is still considered in their mind, to be "chunked" into a memory pattern that does not enable them to differentiate the biomechanical pattern of a WC player serving compared with a biped player serving. Future research should explore the amount of past playing experience to determine if there is a period of biped playing experience that is needed before the VS patterns change.

Table 4 Fixation Location at Each Biomechanical Phase for Reina et al.'s (2007) Study Compared With the WCO Group

Group	Ritual phase	Preparatory phase	Execution phase	Finishing phase
Reina et al. (2007)	GBP	Ball	Ball	Ball
WCO	NDA	Contact	Contact	Ball

Note. WCO = wheelchair only; GBP = general body position; NDA = nondominant arm.

The results of this research touch on athletic, coaching, and performance expertise concepts. Reina et al. (2007) states that "common coaching situations are that wheelchair tennis players train with biped coaches, we should consider that they may be cuing strategies that are not optimal for real-game conditions." The results of this study only partially support this statement as all these players are at the top of WC tennis world rankings. Therefore, could there be two possible VS patterns that are acceptable in WC tennis? Alternatively, as we are only examining one area of expertise, that is, vision and not say physical strength, mental toughness, or flexibility, if one pattern is better than the other, then could the players who do not have the "ideal VS pattern" become even better if they were to adopt the best pattern? Future research should examine the performance statistics of these elite players who have differing VS patterns and compare them with those who have the best return of serve. This is a limitation of this study.

Another limitation of this study is that the video model observed by WCO and WCB participants was a male player. The male participants, in this research, may have played against the model player and may have been more familiar with his serve than the female participants. Although WC tennis players often play mixed doubles, which allows females to view males serving and vice versa, future research should consider female and male models. Future research should also consider examining other past experiences that could influence the groups, such as past sports played.

Future research should examine the long-term memory and learning that has taken place to determine whether there is a time when playing experience is associated with long-term memory of VS patterns. If such patterns need to be overcome, could there be different coaching strategies associated with learning for the first time versus relearning, that is, overcoming an old VS pattern that may not be as advantageous in a new context.

This study uniquely examines wheelers with no prior experience in biped tennis and those with experience in biped tennis. Results reveal significant differences between the groups. These differences may reflect experience and should be considered when coaching and training wheelers.

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