Visual Behavior and Motor Responses of Novice and Experienced Wheelchair Tennis Players Relative to the Service Return

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The purpose of this study was to determine visual behavior and motor responses between experienced and novice wheelchair tennis players relative to the return in tennis. Novice ($n = 7$) and Experienced ($n = 5$) wheelchair tennis players took part in the study. Two series of serves performed to the forehand and the backhand sides were examined in both groups. One series was performed in a video-based setting (two dimensional) and the other one on court (three dimensional). Experienced participants focused initially on the head/shoulders and the free-arm, while novice players focused on the expected ball toss area or followed the ball from the toss to the apex. Results suggest that the experienced players obtain useful information from racket-arm cues during the stroke phase. They also performed faster motor responses as well.

Practice is considered a major contributor to success in sports, but only if that practice is guided by key abilities required by that specific sport (Singer & Janelle, 1999). In order to produce the desired outcomes, it is more important to understand practice and how it should be carried out rather than simply count the duration of such practice in hours or years (Starkes, Helsen, & Jack, 2001). Chamberlain and Coelho (1993) suggest that it would be appropriate to classify experienced and novice athletes according to their anticipation and decision-making abilities rather than their current level of performance. This statement suggests a close relationship between the perceptual and motor abilities of the athletes. A good player must be

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able to attend to the most salient aspects of the opponent’s performance, be able to pick up cues about the opponent’s shot selection, have an ability to anticipate and to make decisions quickly, and then to react (Lees, 2003). Therefore, highly skilled athletes are believed to possess the ability to perceive visual information from an opponent’s motion pattern and use that information to anticipate subsequent events (Shim, Chow, Carlton, & Chae, 2005).

There are various ways to study sport performance. They include both qualitative techniques (such as in-depth interviews and “think aloud” verbal protocols) and quantitative procedures (e.g., pattern recall and recognition tasks, occlusion techniques, pre-cues techniques). In recent years, many studies in adapted sports have involved elite athletes with disabilities in disciplines as physiology (e.g., Goosey-Tolfrey, 2005), psychology (e.g., Cervelló, Hutzler, Reina, Sanz, & Moreno, 2005) and biomechanics (e.g., Vanlandewijck, Theisen, & Daly, 2001). In this study, we will analyze the differences between novice and experienced wheelchair tennis players using eye-tracking technology and through the analysis of the motor responses.

The study of the eye movements can provide insights into relationships between “looking” (or visual fixation) and “seeing” (or paying attention; Moran, 2004). According to Moran, certain inferences can be drawn from the location and duration of the perceiver’s visual fixations. The location of the visual fixations is usually regarded as an index of the relative importance of a given cue within a stimulus display, while the number and duration of fixations recorded (denominated “search rate”) are believed to reflect the information-processing demands placed on the perceiver. Also, visual fixation characteristics are indicative of the perception strategy used by the observer to extract specific information.

In recent years, the differences in the visual behavior of non-disabled athletes/players with different levels of experience in a specific domain have often been studied (e.g., Moran, 2004; Moreno, 2004). Expertise appears to be dependent on perceptual and cognitive skills as well as on physical and motor capabilities (Ward & Williams, 2003). For example, the ability to recognize a motion/play pattern is fundamental to successful performance. Prior experience is as important as the ability to apply existing knowledge to new experiences or play situations (Smeeton, Ward, & Williams, 2004). The experts’ advantage is presumed to lie in their superior knowledge and domain-specific memory skills that are acquired through practice or training (Ericsson & Lehmann, 1996), and they are more able to analyze the information of a novel set of circumstances (Williams, 2000). Also, some authors argue that the more highly skilled performance of experienced players could be due to differences in their perception and decision-making processes, independently of the action processes (Seiler, 2000). Less skilled players may be “cognitively handicapped” by their inability to recognize and respond to certain patterns of play (Moran, 2004).

Some authors suggest that some expert players acquire better visual abilities due to practice (Garland & Barry, 1990), meaning that they move their eyes more efficiently. These abilities could contribute to their improved performance (Abernethy, 1987). Those visual abilities would allow them to process visual information of the scene more quickly, thereby allowing them to improve the probability of performing a correct and effective response by (a) performing the motor responses sooner and (b) providing more information to the decision-making processes, with a higher probability of performing a correct and effective response (Deary...
Temporally constrained situations, like wheelchair tennis, demand that players extract the most valuable pieces of visual information and use them to quickly anticipate the opponent’s action (direction, force, and spin of the serves; Shim et al., 2005). Therefore, experienced players can extract and use this information more effectively than can less skilled ones (Abernethy, 1988). An implication drawn from these findings is that players of disparate skill levels could pursue visual search and cue utilization in different manners.

Although the way in which players pick up cues from their opponents has received special attention in racket sports like tennis, badminton, or squash (see Cauraugh & Janelle, 2002), there are few studies in the literature about visual behavior of wheelchair tennis players (Reina et al., 2004). Studying differences among players with different levels of experience is important in wheelchair tennis, because players of all ages and levels play under the same rules, use the same standardized courts (size and shape), and have the same opportunities to play in the same role (in single matches) and to perform the same strokes (McPherson, 1999). Wheelchair tennis is played on the same court as ambulatory tennis and with the same equipment (e.g., balls, rackets, net). The wheelchair enables the player to use different and unique movements (turns) as an alternative to locomotion typically observed in able-bodied tennis (jumps, slides, or sprints). The wheelchair movements used in wheelchair tennis are similar to wheelchair basketball or wheelchair rugby (Goosey-Tolfrey & Moss, 2005). Ambulatory and wheelchair tennis players use different body parts to arrive at the best position to hit the ball. While ambulatory tennis players use the legs for movement on the court and the hand to swing the racket, wheelchair tennis players utilize the same body part (the hands) to meet both of these demands (Hutzler, 1992; Hutzler, Frigia, & DeLange, 1996). Therefore, there are some adaptations in tennis rules (e.g., double bounce) as well as adapted technical and tactical aspects, including strokes or specific mobility skills that have been implemented in wheelchair tennis (Hutzler et al., 1996; Pollick, 2000; Sanz, 2003).

Results from empirical investigations of various racket sports (Cauraugh & Janelle, 2002) suggests that (a) racket sport performers visually search and use cues provided by opponents in an attempt to minimize decision-making delays; (b) the arm, racket, shoulder and trunk areas of the opposing server are critical locations for information acquisition concerning the type and direction of strokes; (c) expert players generally follow different visual search strategies from novice players; and (d) experts are more attuned to advanced (pre-flight) cues (e.g., ball tossing shoulder angle, ball toss over the head or forward, and angle of racket face) that occur earlier in the stroke sequence than novices, allowing greater speed and accuracy in predicting stroke type and location.

Some authors state that previous experiences underlie the visual paths and the decision-making processes, as indicated by the significant differences between experts and novices in the location and duration of their visual fixations (e.g., Helsen & Pauwels, 1993). In contrast, Ripoll (1991) states that differences between expert and novice able-bodied athletes in visual scanning mode will only appear when the task is time constrained, some events of the movement/pattern are occluded or quicker responses are required, which are often experienced under real-life conditions. However, real-life settings are difficult to reproduce experimentally, and often constrain the expert’s typical responses to either using different information
to create a response or preventing access to information normally available in the
performance context (Abernethy, Thomas, & Thomas, 1993). Also, the perception
and action processes should be understood to be interdependent (McMorris & Bea-
zeley, 1997), since these actions are determined by previous perception processes.
Studying these processes separately could create an artificial situation that does
not offer a reliable measure of the players’ experience in their sport environment
(Chamberlain & Coelho, 1993).

Therefore, the measures of this study were carried out in situations that replicate
real game conditions, where players could perform their responses under pressure
game situations. The setting was made more natural by using a large video-based
system and by instructing the players to perform a tennis skill. Comparisons were
made between the court (three-dimensional) and video-based (two-dimensional)
conditions (Reina, Moreno, Sanz, Damas, & Luis, 2006). Therefore, the aim of
this study was to analyze the visual search behavior and motor responses of novice
and experienced wheelchair tennis players in real-life and simulated (video-based)
conditions versus individuals serving in both ambulatory and wheelchair modes.

Method

Participants

Seven novice (two female and five male) and five experienced (one female and
four male) wheelchair tennis players participated in this study. They were 24.14 ±
5.46 and 28.8 ± 5.8 years old, respectively. The players of the first group (Novices
= N) had no more than 30 months of practice in wheelchair tennis (1.78 ± 0.7
years) and no participation in national championships. One of the participants
was a trans-femoral amputee, and the others had spinal cord injuries at levels T2,
T8, T11 (2), L1, and L3. The participants of the second group (Experienced = E)
had practiced wheelchair tennis for more than three years in Tennis Sport Acad-
emies (5.8 ± 2.17 years), have participated in National Wheelchair Tennis Master
Competition (for the highest eight ranked players), and participated in the World
Team Cup Championships (once or more times). All participants of this group had
spinal cord injuries at levels T10, T11, T12, L1, and L3. A common criterion for
participants in both groups was that they never regularly practiced tennis before
their acquired disability. Participants completed an informed consent form approved
by the University Office for Research Ethics.

Instrumentation

To record the visual behavior, we employed the ASL Eye Tracking System SE5000
(Applied Sciences Laboratories™). It is a video-based monocular system that
measures the perceiver’s point of gaze with respect to video images recorded by
an infra-red eye camera and a scene camera. Displacement data from the left pupil
and cornea are recorded by the eye camera, and the result is a precise point of gaze
over the scene image. This image was then recorded using a video recorder (Sony
DVCAM DSR-30P) for a more detailed frame-to-frame analysis at 50 frames/
sec data frequency by a SVHS video recorder (Panasonic NV-HS1000ECP). As
suggested by Moran (2004), certain inferences can be drawn from the location
and duration of the perceiver’s visual fixations, particularly (a) the location of a fixation is usually regarded as an index of the relative importance of a given cue within a stimulus display, and (b) the number and duration of fixations recorded (search rate) are believed to reflect the information-processing demands placed on the perceiver.

An automated system was employed to acquire data about the motor response and its precision (see Moreno, Reina, Luis, Damas, & Sabido, 2003). The players must hit two targets located to their right (forehand stroke) and to their left (backhand stroke). A wireless microphone (Shure Instruments Inc. T3 Receiver and trunk T11-ND) records the sound of the hit in the serve action. The hit activates a sound switch (Lafayette 63040; signal 1). Once the participants decided their response, they lifted the hand of a pressure-sensitive badge (signal 2), and they cut off the light beam of a photoelectric cell (Omron E3S-AT11). These light beams are parallel to the hit surfaces (signals 3 or 4). The devices were plugged into a computer with software to acquire data about reaction time (signal 2—signal 1), movement time (signal 3/4—signal 2) and response time (signal 3/4—signal 1; see Figure 1).

To simulate the return of service action in the two-dimensional condition, we employed a digital video-recorder (Sony DCR-TRV20E), a multimedia projector (Hitachi CP-S310W), and a large projection screen (3x5m).

**Procedure**

All participants were examined in a simulated return to serve situation against real-life players (three-dimensional) as well as those projected on a large screen (two-dimensional). Two skilled wheelchair tennis players and two ambulatory tennis players were video-recorded for the films in the two-dimensional situation, and they performed the serves in the three-dimensional situation. The serves were directed to the forehand side or the backhand side. Top-Spin serves were performed, 24

![Figure 1 — Instrumentation for the motor response data (RT = reaction time, MT = movement time, ReT = response time).](image-url)
serves in random order for each setting (court and video-projection). Each server performed 6 serves against each participant, three directed for the forehand side and the other three to the backhand side. The players put their dominant hand on the pressure-sensitive badge located before them, and they responded by hitting right or left targets. The participants were told to respond in a quick and precise way when they were sure about the direction of the ball. Both study situations took place in the same sport setting. Participants were randomly assigned to either a 2D-3D or 3D-2D conditions. The serves were counterbalanced so that half of each group observed the sequence A-W-A-W-A, while the other half observed the sequence W-A-W-A-W (A = ambulatory; W = wheeler).

**Data Reduction and Analysis**

Two dependent variables were used to identify the visual behavior (search rate): (a) Number of visual fixations (NF), which was defined as the number of times the gaze of a player remains in a location more than 60 ms and (b) the Time of visual fixation (TF), which was indicated by the percentage (%) of time placed in that location with regard to the total time on that location for the complete motion or a phase. The visual behavior of the players was analyzed for the complete motion of the serves and the following phases: ball toss (A), preparatory phase (B), hitting phase (C), and ball’s flight phase (D; see Figure 2). By considering the motion as a sum of the different phases, it allowed us to analyze the visual search strategy carried out by the players against the serve (Nagano, Kato, & Fukuda, 2004). Also, the number and duration of the visual fixations were analyzed on following locations: ball (BA); racket (RA); perform arm (PA), which is the arm that holds the racket including the shoulder joint, upper arm, elbow joint, forearm, wrist joint, and the hand; free arm (FA), which is the arm that performs the ball toss including the shoulder joint, arm, elbow joint, forearm, wrist joint, and hand; head (HE); trunk (TR); hips (HI); legs (LE); feet (FE), which includes both feet and ankle joints; and wheelchair (WH). These locations were grouped in second order categories: enhanced free arm (EFA = FA + BA in phase A); arm-racket (AR = RA + PA); upper body (UB = FA + HE + TR); lower body (LB = HI + LE + FE + WH, only in wheelchair tennis servers); and enhanced ball (EBA = BA + several areas near its path; see Figure 2). Three other locations were proposed for the ball’s flight phase: (a) “HA” (hitting area, where the ball’s hit takes place and the point where the gaze remains until the first saccade to follow its path); (b) “BB” (behind ball, where the gaze does not reach the ball’s position); and (c) “AB” (ahead ball, where the point of gaze scans advanced areas of the ball’s position).

The ability to detect visual stimuli were analyzed by measuring reaction time (RT), movement time (MT), and response time (ReT) as previously described. Due to the number of participants in the study, a Kolmogorov-Smirnov test was used to determine whether or not a parametric analysis was able to be conducted. A 3-way ANOVA (2 within-subject variables—server position and dimensionality—and 1 between-group factor—experience) was conducted. However, we focus our discussion on the differences between-groups. To avoid possible error rates for comparisons in the ANOVA analysis, a correction to the degrees of freedom was applied through a Greenhouse-Geisser follow-up analysis. Finally, a Pearson correlation analysis was conducted between the visual behavior and motor response scores.
Results

Figures 3 and 4 illustrate the visual fixation time on each grouped location, where two common aspects for both groups (experienced and novices wheelchair tennis players) and settings can be highlighted; the ball is the location with highest scores, and the lower body received less attention and visual fixations. It should be kept in mind that the values for HA, AB, and BB are only for phase D.

On the other hand, considering each phase of the motion (Figures 5 and 6), the most important location in phase A was the upper body (shoulders, head, upper limbs, and trunk) and the free-arm. Phase B showed that the ball was the location with the highest scores of visual fixation, although we should consider the number of visual fixations on this location (N = 1.06 ± 0.53; E = 1.25 ± 0.18) with regard to other locations such as the free-arm (N = 0.26 ± 0.19; E = 0.33 ± 0.24), the arm-racket limb (N = 0.53 ± 0.83; E = 0.37 ± 0.4), or the upper body (N = 0.53 ± 0.56; E = 0.49 ± 0.41). Those high values of visual fixation were obtained with a smaller search rate, distributed with the other grouped locations. Higher time of visual fixations on the arm-racket limb was obtained, and little attention was paid to the lower body. In phase C, the ball was again the location with higher scores of visual fixation, although the arm-racket limb received more attention than in previous phases. Without forgetting the short duration of this phase, the number of visual fixations carried out in this phase on the arm-racket limb (N = 0.33 ± 0.32; E = 0.38 ± 0.42) and the ball (N = 0.88 ± 0.4; E = 0.9 ± 0.22) are characterized by a short duration. Therefore, the participants can follow the ball in its path from the apex to the hitting area (higher time of visual fixation on BA), or to follow the motion of the arm-racket limb from the preparatory phase to the hitting phase (higher time of visual fixation on RA).

In phase D, the ball was the location with the highest scores of visual fixation for number (N = 2.69 ± 0.85; E = 2.94 ± 1.03) as well as time of visual fixation (N = 58.1 ± 19.95%; E = 53.98 ± 20.66%). The second location with high scores of NF in this phase was the BB area (N = 0.89 ± 0.44; E = 1.11 ± 0.48), followed by
Figure 3 — Novice and experienced wheelchair participant’s time of visual fixation (TF %) on the grouped locations in video-based conditions (watching wheeler or ambulatory servers; EFA = enhanced free arm, AR = arm-racket, UB = upper body, LB = lower body, EBA = enhanced ball, HA = hitting area, BB = behind ball, AB = ahead ball).

Figure 4 — Novice and experienced wheelchair participant’s time of visual fixation (TF %) on the grouped locations in real-life conditions against watching wheeler or ambulatory servers (EFA = enhanced free arm, AR = arm-racket, UB = upper body, LB = lower body, EBA = enhanced ball, HA = hitting area, BB = behind ball, AB = ahead ball).
the HA area \( (N = 0.79 \pm 0.24; E = 0.76 \pm 0.22) \), although the time of visual fixation was higher for the hitting area \( (N = 26.41 \pm 10.22\%; E = 24 \pm 10.04\%) \) than for the area behind the ball \( (N = 12.24 \pm 7.16\%; E = 15.5 \pm 8.52\%) \).

A detailed description of visual fixation times during the different phases of the serve’s motion can be observed for the video-based (Figure 5) and real-life conditions (Figure 6), against tennis and wheelchair tennis servers. The scores of the areas with the highest number and time of visual fixations are shaded for each phase.

Significant differences were obtained for the time of visual fixation on the upper body, in the video-based setting against wheeler servers, for the complete motion of the serve, \( F(1, 9) = 5.56; p < 0.05; \eta^2 = 0.38 \), and for the ball toss phase, \( F(1, 9) = 14.31; p < 0.01; \eta^2 = 0.64 \). For the latter phase, experienced players showed higher scores on that location \( (79.66 \pm 10.84\%) \) than did novice players \( (54.85 \pm 8.52\%) \). Significant differences were obtained for the time of visual fixation on the racket in phase C for the serves performed by ambulatory players, \( F(1, 9) = 5.8; p < 0.05; \eta^2 = 0.39 \), with higher scores for the experienced players \( (5.89 \pm 4.3\%) \) than for the novices \( (1.22 \pm 1.91\%) \).
In the court (real-life) setting against wheeler servers, significant differences were obtained for the time of visual fixation on the upper body in the ball toss phase, $F(1, 9) = 6.6; p < 0.05; \eta^2 = 0.42$, with higher scores for the experienced group ($77.67 \pm 10.79\%$) rather than for the novices ($50.39 \pm 21.47\%$), similar to the video-based situation. Significant differences for the TF on the head were also obtained for the complete motion, $F(1, 9) = 8.53; p < 0.05; \eta^2 = 0.49$, and for the ball toss phase, $F(1, 9) = 9.11; p < 0.05; \eta^2 = 0.50$, with higher scores always being obtained by the experienced players ($N = 7.42 \pm 2.13\%; E = 13.46 \pm 4.54\% / N = 23.77 \pm 7.63\%; E = 41.91 \pm 12.2\%$). On court, against ambulatory servers, no significant differences were obtained.

Regarding the motor responses, the experienced wheelchair tennis players generally showed faster reaction times than did the novices (Figure 7), except in the video-based setting against ambulatory servers, in the serves performed to the forehand ($N = 206 \pm 86; E = 212 \pm 38\ ms$), and for the backhand ($N = 199 \pm 99; E = 223 \pm 57\ ms$). This happens again for the scores of movement time, although only for the serves directed to the backhand in the two-dimensional situation against wheeler servers ($N = 205 \pm 54; E = 214 \pm 90\ ms$). Therefore, only in the
video-based situation watching ambulatory servers did the novice players respond more quickly than the experienced ones in the forehand (N = 371 ± 107; E = 377 ± 101 ms) and backhand responses (N = 405 ± 125; E = 471 ± 120 ms). The ANOVA showed significant differences in motor response values for the serves directed at the forehand on court setting. In reaction to the serves performed by wheelchair tennis players, significant differences were obtained for the reaction time, $F(1, 10) = 7.95; p < 0.05; \eta^2 = 0.44$ and the total response, $F(1, 10) = 6.12; p < 0.05; \eta^2 = 0.38$. In reaction to the serves performed by ambulatory servers, significant differences were only obtained for the reaction time, $F(1, 10) = 6.15; p < 0.05; \eta^2 = 0.38$.

The correlation analysis revealed that in the two-dimensional situation, the novice players showed a positive correlation between the time of visual fixation on the upper body in phase C and the total response, against wheelchair (r = .861; p < 0.05) and ambulatory servers (r = .875; p < 0.05), where they also showed another correlation with the total response (r = .878; p < 0.05). On the other hand, in serves performed by ambulatory servers, the experienced players produced a negative correlation (r = -.977; p < 0.05) between the time of visual fixation on the upper body and the total response time. There was also a negative correlation between the time of visual fixation on the upper body in the preparatory phase and the movement time (r = -.954; p < 0.05), although only for the serves performed by ambulatory servers. It is noteworthy that against wheelchair tennis servers, the experienced group produced another negative correlation between the time of visual fixation on the racket and the movement time (r = -.971; p < 0.05), while against ambulatory servers, the correlation was obtained between the arm-racket limb and the total response time (r = -.977; p < 0.05).

**Discussion**

Differences in visual behavior and motor responses between experienced and novice wheelchair tennis players have been studied in real-life and video-based conditions. Eye tracking technology was used to acquire data of the visual path, and an automated system was employed to measure the motor responses of the participants against the serves performed by ambulatory and wheelchair tennis servers.

**Visual Behavior (Search Rate)**

In the two-dimensional setting, the results revealed that the novice wheelchair tennis players utilized less time in visual fixation to obtain information about the upper body, and they carried out a longer pursuit of the ball’s path. During the ball toss phase, the experienced group observed the free-arm and the head/shoulders area longer, locations that could give players information about the direction of the serve (Moreno & Oña, 1998). Similar results were obtained in the court situation. Our results are in accordance with findings obtained in another study carried with ambulatory tennis players (Williams, Singer, & Weigelt, 1998) in which the more skilled players focused initially on the arm-racket shoulder and then tracked the ball as it was tossed into the air. The lower ranked players in that study focused on the expected ball toss area or followed the ball from toss to apex. Contrasting results were obtained in a study carried out by Goulet, Bard, and Fleury (1989).
Figure 7 — Scores of reaction time and movement time for the serves performed to the forehand and backhand sides (2D = video-based conditions, 3D = real-life conditions, WT = wheeler servers, A = ambulatory servers).
with ambulatory tennis players. In a preliminary phase, the expert tennis players paid attention to indexes related to general body position, while the novice players considered the head as the most informative area. It is likely that this preparatory phase can help less skilled players select relevant information in later phases. The observation of the head/shoulders area as a “pivot point” is also understandable, as players could move their point of gaze to other distal areas (e.g., ball or racket) with a shorter ocular movement. This fact permits players to obtain information of their opponent from other locations using parafoveal vision, which covers a visual arc of some 10 degrees (Savelsbergh, Williams, Van der Kamp, & Ward, 2002).

The results obtained from the correlation analysis for the upper body and the arm-racket limb is interesting. The hitting phase is considered as the foremost time to obtain key information about the serve’s direction, fundamentally from the motion of the racket prior to the stroke (Farrow & Abernethy, 2002; Moreno & Oña, 1998). That fact could be due to more knowledge of serve kinematics (longer practice during their sport life) or perhaps learning how to obtain key information that helps predict the serve’s direction. Therefore, the novice players would use more visual time in pursuing the ball, and it would be more difficult to obtain key information about the hit. This novice player behavior has been found in other sports such as volleyball (Allard & Starkes, 1980), where the players pursued the ball instead of other locations of the scene or opponents. These results are also supported by the findings of Goulet and colleagues (1989), where the experts paid attention to the racket during the hitting phase, while the novice players observed other locations.

From our findings, it appears that the experienced players prefer a “holistic” visual search strategy (inter-events visual pattern), while the novices prefer observing informative cues according to their order of appearance (linear visual search pattern; Ripoll, 1991; Ripoll, Kerlirzin, Stein, & Reine, 1995). Therefore, in spite of the similarity between visual search strategies developed in both groups, it is possible that the skilled players are aware of key informative cues (e.g., arm-racket motion in the hitting phase) that enable them to perform faster motor responses. Although the distal cues of the racket and the ball’s hit are more reliable and specific than proximal cues, some information from the arm-racket limb previous to the impact could contribute to the anticipation of the ball’s path (Abernethy, 1989), and the players would have “extra-time” for better decision making and motor response performance (Tenenbaum, Yuval, Elbaz, Bar-Eli, & Weinberg, 1993). If novice players do not know the potential information of some cues, such as the arm-racket orienteering during the hitting, they will not obtain any advantage by inferring the serve’s direction. They would observe the ball like a reliable informative cue, leading to a slower motor response (Chamberlain & Coelho, 1993).

A practical implication for wheelchair tennis is that if the player knows the ball’s direction early on, he or she would move toward the direction of the service bounce with more time, to orient the wheelchair, and to acquire a better position to perform the return of service. Based on interview data, this strategy has been described by Hutzler (1992) under the label “watch the opponent,” suggesting that the player watches the racket in the opponent’s hand to predict in advance the height of the serve and the direction and location of the ball bounce, and it appears to be a key strategy to the problem solving of positioning in wheelchair tennis. Based on Goulet et al. (1989) as well as Bard, Fleury, and Goulet (1994), it is proposed that the differences between expert and novice players are not apparent in the visual
search strategy but in the information that players extract from visual cues. Unlike skilled tennis players, novice players are not able to predict the location, speed, and spin of the ball’s bounce from such factors as racket position, shoulder orientation, or load transferring (only for the upper body in wheelchair tennis players).

This study suggests that it is not sufficient for coaches to instruct novice players to restrict their visual search to a certain location, such as the arm-racket area. Rather, data suggest that players should be instructed on how to understand the relationship between the kinematics and later events such as the path, speed, or spin of the ball (Abernethy & Wollstein, 1989). The tennis serve is a proximal-to-distal technical stroke, and there is only uncertainty about the ball’s direction and whether it will require a forehand or backhand stroke. This could be the reason behind the few differences obtained in the results between experienced and novice players. Nevertheless, some limitations of the study should be improved, such as the limited number of participants or the stationary response setting.

With regard to the position of the servers, the higher visual fixation scores on the ball in the serves performed by wheeler servers could be due to the grabbing of the rim of the wheelchair with the free arm in order to gain stability. Results obtained for the free-arm and the ball in the ball toss phase, with higher mean values on ambulatory servers, could support this statement. Therefore, against wheeler servers, the players generally perform a longer pursuit of the ball’s trajectory, and they show lower fixations on the area where the racket hits the ball. Furthermore, they are quicker in pursuing the ball’s path because wheelchair opponents’ serves are slower than ambulatory performers’ serves. This statement is supported by higher fixations on advanced areas of the flight ball’s position for the serves performed by wheeler servers. On the other hand, higher fixations were obtained in the area behind the ball’s flight position for the serves performed by ambulatory servers. Since a common coaching situation is that wheelchair tennis players train with ambulatory coaches/instructors, we should consider that they may be using cuing strategies that are not optimal for real-game conditions.

**Motor Responses**

Regarding the results obtained for the motor responses scores, we have found that the more skilled players generally responded faster than the novice players. This is in accordance with results of other studies carried out in sports where participants perform a motor response against a direct opponent (Helsen & Pauwels, 1993; Shim et al., 2005; Williams & Davids, 1998). These findings suggest that experienced players may have better knowledge of serve kinematics as a result of their greater experience, which in turn makes them able to respond more quickly. Experienced players have better skills in obtaining, codifying, and interpreting the information of their opponents, which could help them in their decision making (Abernethy, Gill, Parks, & Packer, 2001), because they have more time to decide the correct response and (Shim et al., 2005), therefore perform it more quickly. This hypothesis is supported by the results of the correlation analysis between visual and motor behavior data. The negative correlation between the visual fixation times on the upper body during the hitting phase (for the experienced group) could indicate that a longer visual fixation on the arm-racket limb contributes to a faster response. It could also be interpreted that for both groups, the arm-racket limb was important,
but only the experienced players were able to take advantage of this information. Also contributing to this hypothesis are the negative correlations of the experienced group during the preparatory phase with regard to the upper body, supporting our notion that experienced players could obtain relevant information from the area preceding the ball’s hit (Farrow & Abernethy, 2002), such as racket trajectory, potential impact area, racket orientation, or potential spin.

Since significant differences in the reaction times were only obtained for the serves performed by ambulatory servers, however, it is possible that the “cognitive advantage” of the experienced players with regard to the novice ones is smaller when the response was performed against wheeler servers. The faster reaction time scores of the more skilled participants could support their higher cognitive ability to interpret the information of the opponent (Schweizer, 1998). Once the player knows the ball’s direction, he or she would be able to perform a faster response (Farrow, Chivers, Hardingham, & Sachse, 1998), since some information presented before the ball’s hit could contribute to reduce the reaction time (Abernethy, 1991). Nevertheless, other authors notice that more skilled performance of skilled players may be due to a better interpretation of the first information of the ball’s flight (Buckolz, Prapavesis, & Fairs, 1988). The skilled players are able to follow the flight of the ball more smoothly than the less skilled players (Williams et al., 1998). According to Abernethy (1991), a relationship between the reaction and the experience of the players could be established. Furthermore, the best values in the reaction response against ambulatory servers could be due to the lack of information of knees flexion in wheeler servers, where the upper body position is directly linked to the lower body (Goulet et al., 1989). Furthermore, wheeler servers could have a restricted torso motion due to their position on the wheelchair, and they could show some cues about the ball’s direction later than the ambulatory servers. The serve’s speed (faster in ambulatory servers) could be other reason of these results.

With regard to the effect of the dimensionality (Reina et al., 2006), Shim and Carlton (1999) observed a progressive deterioration in expert performance across “live” and film conditions, whereas novices did not significantly differ across viewing conditions. Although there is no further research into the effect of dimensionality of the display on visual search strategies in sport, different studies have demonstrated the expert’s ability to employ perceptual resources more efficiently in real world conditions than in video-based ones (Abernethy et al., 2001; Chamberlain & Coelho, 1993; Vickers & Adolphe, 1997). As a result of their more-refined task-specific knowledge structures and improved strategic processing of information, experts are able to interpret events encountered in circumstances similar to those previously experienced (Williams, 2000).

Since authors purport the importance of perceptive training in tennis (e.g., Williams, Ward, Knowles, & Smeeton, 2002), we recommend conducting future studies to establish the outcomes of specific training techniques of anticipation such as visual occlusion, point-light displays, or pre-cue techniques. Acquisition and/or processing of the information regarding kinematics could be improved through self reports on where attention is directed.

References

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**Endnote**

1Original data in milliseconds (msec.) have been transferred in percentage of time dedicated in each location of the server, ball or racket.

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