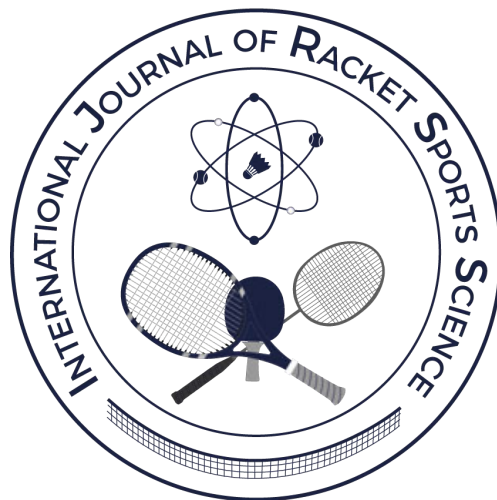


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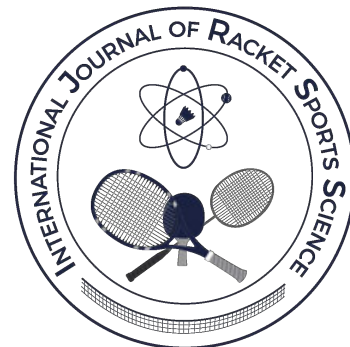
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# The influence of expertise on anticipation of badminton single serves

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## Abstract

Badminton is a fast racket sport and requires players to develop highly advanced anticipation skills. Research has identified differences in the way that experts badminton players fixate their gaze during play. Investigating eye movement patterns in badminton players, may help to understand how expertise is associated with better anticipation abilities. All previous research on the return of a badminton serve has been solely made up of laboratory-based components and consequently it is arguable as to whether athletic skills are transferable from real-life settings. This study investigated the return of a badminton serve in a game setting. Expertise and type of serve acted as the independent variables when investigating between-group differences during fixation development. The experts (N=23) and novices (N=11) were asked to return forehand serves, whilst wearing a mobile eye tracker, for recording eye movement data for refixations, first visual intake duration and dwell time. The results demonstrated that both experts and novices targeted similar fixation sites. However, during the short serve, experts were found to make more fixations and longer fixation durations, suggesting that experts may use their pre-existing knowledge about badminton in anticipating serve returns.

Keywords: *Badminton, Expertise, Fixation development, Eye movements, Anticipation*

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## Introduction

Badminton has been an Olympic sport since the 1992 Olympic Games and is generally considered the world's fastest racket sport. The sport demands players to have exceptionally quick responses, as shuttles reach speeds of over 400 km/h (Maæka & Cych, 2011). The world record for the fastest smash of 419 km/h is currently held by Viktor Axelsen (Axelsen smashede sig til rekord i All England-finalen: 419 km/t, 2019).

The high shuttle speed, means that badminton players are limited in their ability to track it before it reaches what is known as the point of interception (Müller & Abernethy, 2012), i.e. the moment when the racket touches the shuttle. Research has compared data between experts and novices to understand the naturally occurring behaviours in badminton players prior to this point. Rudin and Sharipan (2016) examined badminton players in relation to non-badminton players, by asking them to follow an alternated light fixation in order to measure eye movement differences between the two groups. They reported that badminton players produce saccadic eye movements that were more accurate than non-badminton players.

Sport research has explored the topic of gaze in sports and has defined gaze as a means of gaining information for the purpose of avoiding making mistakes (Najemnik & Geisler, 2005). Gaze may therefore be another word for target fixation (Vickers, 1996). Being able to anticipate an opponent's movement accordingly is a skill highly valued in badminton, as players only have a very short amount of time to adjust a stroke once the movement has commenced (Müller & Abernethy, 2012). Badminton players may use information provided by the opponent towards completing accurate and appropriate countermoves when responding to the moves of the opponent. There may therefore be some points on the opponent's body that provide more information than other points. We refer to these points as fixation sites or areas of interest (AOI), as this is where the badminton player chooses to fixate their eye movements.

To the knowledge of the authors, four studies have considered the influence of AOI during badminton games. The first, that by Abernethy and Russell (1987), investigated expert and novice badminton players and the ability to predict, i.e. anticipate, the shuttle end location. Participants viewed videos of badminton serves and marked the end location of a shuttle on a piece of paper (Abernethy & Russell, 1987). The results showed that experts were able to make use of the information available earlier (167 s before the shuttle made contact with the racket), in comparison to the novices (83 s before shuttle-racket contact) when anticipating the direction of the shuttle (Abernethy & Russell, 1987). A more recent badminton study was completed by Abernethy and Zawi (2007). They replicated the video-viewing procedures by Abernethy and Russell (1987) in expert and novice badminton players but added the component of occlusion. The videos were edited to display either only the racket and the shuttle, only the arm and the shuttle, only the upper body and the shuttle or only the lower body and the shuttle. They reported that both experts and novices were able to correctly anticipate the direction of the shuttle regardless of whether or not information was concealed from them (Abernethy & Zawi, 2007). What set the groups apart however, was that experts were found to extract more information provided by the racket and lower body of the opponent, in comparison to novices who derived the most information from the arm of the opponent. The data may be more transferable to real-life scenarios if participants were asked to physically respond to the shot shown in the video, as opposed to noting down the direction of the shuttle on paper. Alder, Ford, Causer and Williams (2014) further investigated a badminton player's ability to anticipate the landing of a badminton shot. They asked expert and novice badminton players to physically (by moving towards the place they thought the shuttle would land) and verbally respond to a serve they viewed on a life-sized screen. Eye movements were recorded in both the experts and novice observers. The results were in agreement with the two previous studies (Abernethy & Russell, 1987; Abernethy & Zawi, 2007), proposing that experts show

greater anticipation skills than novices (Alder et al., 2014). Experts were again found to fixate most on the racket, in correct trials, and the novices were found to fixate most on the wrist of the opponent, for incorrect trials (Alder et al., 2014). However, similar to the two previous studies, the players were still asked to pretend to respond and it may be questioned whether they experienced true match like feelings and thus produced reliable data.

The only study to measure eye movements while players were actually on court was recently published by Chia, Burns, Barrett and Chow (2017). The researchers examined visual behaviours by eye tracking badminton single players whilst they served. They reported that experts had a longer preparation stage than novices when serving and because of this, they made more and longer fixations and fixated on a wider range of locations in comparison to novices (Chia et al., 2017). All four studies mentioned above have appropriately investigated badminton player's ability to anticipate and make fixations for high level badminton games. However, the studies are lacking both data transferrable to real-life badminton games and eye movement data on the return of a badminton serve.

Studies in sport examining the allocation of attention towards anticipation are limited by the need to ask participants to look for a certain object or at a certain point of interest (Kibele, 2006). This links closely to the idea of a coach telling a player what to do, or where to look. In the well-known experiment by Simons and Chabris (1999), the researchers investigated the concept of inattention blindness and found that participants failed to notice other important information if they were asked to search for something specific. In other words, asking participants to fixate their vision towards a specific point may hinder the development of the natural fixations that are used in a real-life game of badminton. Hence, real-life experiments investigating the relation between perception, anticipation and oculomotor strategy and movements are required.

This study examines the eye movement patterns made by expert and novice badminton players returning serves on a badminton court. Based on the

literature review provided we hypothesise that experts will, in comparison to novices, make a greater number of refixations, longer fixation durations and they will fixate on different AOI.

## Methods

### *Participants*

The study contained a total of 34 badminton players, after two were excluded (one beginner and one national player) due to lack of data. They were beginners (five females and six males,  $M= 11.73$  years of age,  $SD= 0.91$  years), youth coaches (seven females and two males,  $M= 17.33$  years,  $SD= 2.60$  years), college players (three females and seven males,  $M= 17.8$  years,  $SD= 1.23$  years) and lastly national players (one female and three males,  $M= 21.50$  years,  $SD= 4.43$  years). The coaches, college players and the national players were grouped as experts because they had a minimum of three years of experience competing in badminton. The beginners had no experience in competitive badminton. All players, except for one male badminton college player, were right-handed and no significant injuries were present in the players. All participants had reported normal vision.

### *Ethics*

The researcher passed the safeguarding check (the Disclosure and Barring Service) before the study, as some of the participants were under the age of 18. Guardians were asked to sign consent forms on the behalf of participants under the age of 18 and participants were debriefed together with their guardian. The study was approved by the Research Ethics Committee of the Faculty of Arts and Human Sciences at Kingston University, London.

### *Material*

SMI mobile eye tracking glasses (SMI ETG 2w, SensoMotoric Instruments, Teltow, Germany) were used in the study as they examine accurate representations of eye movement patterns in real-life settings. The mobile eye trackers permitted participants complete mobility with the lightweight

glasses (47 g) and they further supplied high resolution (1280x960) videos and 60 Hz binocular tracking data. The glasses are attached to a recording box via a cable. The recording box was placed around the waist of the badminton player using a normal waist belt and the cable was placed on the back of the player away from their arms. All participants were fitted with the belt accordingly and instructed to warm up while wearing the belt and eye tracker to familiarise themselves with the possible obstructions from the device. No participants expressed discomfort nor feeling restricted by the belt nor wearing the glasses.

Calibration of the eye tracker was necessary for accurate measurements. While wearing the eye trackers, participants were asked to focus on a point roughly 1.5 m away from where they were standing. The researcher used the recording device to allocate point of gaze to the point on which the participants were fixating. The experiment commenced after calibration had been successfully completed.

### *Procedure*

Prior to the experiment, participants were informed that they would be returning a variety of single serves during a badminton single match. Consent forms were either signed by the participants themselves or by a guardian, if the participant was under the age of 18 years old. The experiment required an opponent, i.e. a server, to serve the required serves to the participants. The server was either an expert badminton player, with a minimum of three years of either competition experience, or a coach, with a minimum of three years of coaching experience, and was therefore deemed capable of completing technically correct badminton serves. Each trial of the study followed a procedure created to stimulate a match-like environment and the standard badminton serve rules applied in the experiment. Overall, the participants returned 40 serves, whereof the first 20 consisted of long forehand serves and the last 20 were short forehand serves, and the trials followed the pattern of: serve-return-hit-hit. The data analysis concerned only the eye movement patterns produced by the participant during the return of the serve, but the remaining hits were vital as they simulated realistic badminton scenarios. The serve

return phase, in which eye movements were recorded, took place from when the server started the motion until the point of interception. Any incorrect serves or incorrect serve returns were replayed until 20 correct trials had been recorded by the eye tracker for each serve type condition. Breaks were introduced as required. The experiment took a total of 20-30 min per participant and concluded with debriefing. Participants under 18 years old were debriefed along with their guardian.

### *Data Analysis*

The study followed a between-groups design with refixations (the number of times participants returned to one of the fixation sites), first visual intake durations (the amount of time the participants spent looking in the area of interest at the first glance) and dwell times (total time spent looking at the one of the areas of interest) as the dependent variables; and type of serve condition (long forehand serve and short forehand serve) and expertise level (experts and beginners) as independent variables.

The areas of interest (AOI) used in the analysis originated from previous studies on eye tracking of badminton players. A total of 11 AOI were considered of importance for serve returns: the shuttle, the racket, wrists, elbows, arms, shoulders, head, belly, hips, legs, feet (see Figure 1). All data were evaluated for normality using the Shaphiro-Wilk's test at  $p < 0.05$ , and the Mann-Whitney U test was chosen to test for differences between independent variables (part1) with a significance level of  $p < 0.05$ .

Subsequently (part 2), the AOI were grouped into three general sites: upper body fixation sites (elbow, arm, shoulder, head, belly), lower body fixation sites (hips, legs, feet) and fixation sites that were located on areas away from the main part of the body of the opponent (shuttle, racket head, wrist). This was because coaches, when coaching badminton techniques, separate upper body motions from lower body motions. The number of refixations, first visual intake durations and dwell times were used to indicate the level of importance of the AOI to the participants' attentional behaviour. It is assumed that one AOI is considered more important than another AOI if

participants either return frequently (i.e. make more refixations) to the AOI or devote longer fixation durations (i.e. longer first visual intake durations and longer dwell times) towards the AOI.

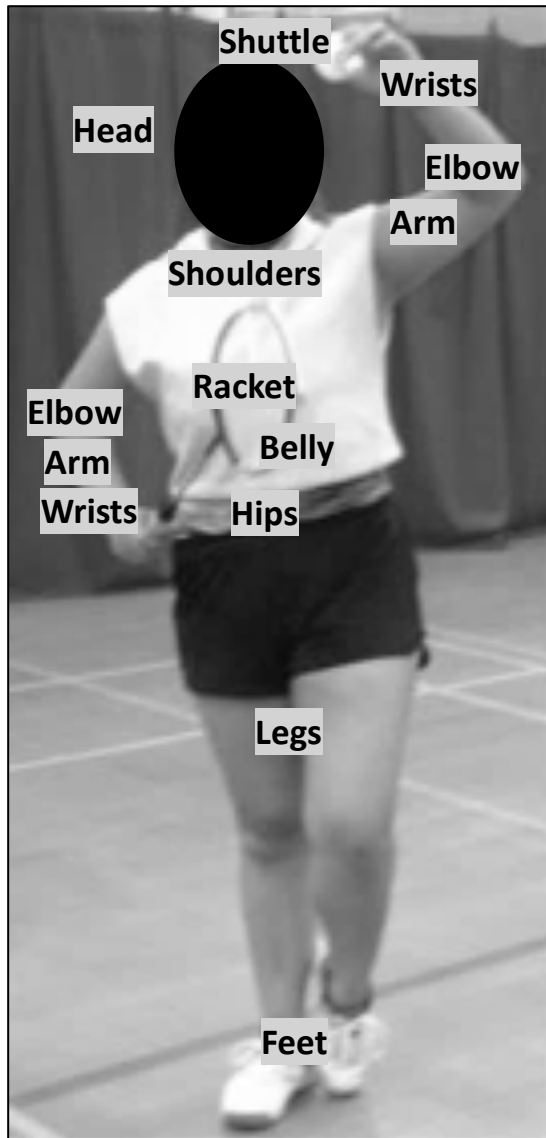


Figure 1. The 11 areas of interest (AOI) analysed.

## Results

### Part 1

The mean values for refixations (Figure 2), first visual intake durations (Figure 3) and dwell time

(Figure 4) are all higher for the experts in comparison to the novices. For refixations, the exception is found for the AOI located on the legs for the long serve and the elbow and arm for the short serve. For first visual intake durations, the exception is the shuttle, racket head and the feet for the long serve and the wrist for the short serve. For dwell time, the exception is the shuttle, racket head and the feet for the long serve and the wrist for the short serve. Qualitatively, the experts are found to show higher mean values for the head during the long serve and for the shoulder during the short serve (see Figure 2, Figure 3 and Figure 4). The novices, in comparison, show higher mean values for the legs (see Figure 2 and Figure 4) and the shuttle (see Figure 3) during the long serve condition and, similarly to the experts, the shoulder (see Figure 2, Figure 3 and Figure 4) during the short serve condition.

Furthermore, the experts appeared to show no fixation patterns for the feet (see Figure 2 and Figure 4) or low fixation patterns for the feet (see Figure 3) for the long serve condition and low fixation patterns for the feet (see Figure 2 and Figure 4) and the wrist (see Figure 3) for the short serve condition. Lastly, the novices show no fixation patterns for the shuttle and the wrist (see Figure 2 and Figure 4) and low fixation patterns for the wrist (see Figure 3) for the long serve condition and no fixation patterns for the racket head, wrist, head or feet (see Figure 2) and low fixation patterns for the elbow, arm and head (see Figure 3) and the feet, head and racket head (see Figure 4).

The data were found to be non-normally distributed. The Mann-Whitney U test revealed significant differences between levels of expertise for the short serve (see highlighted in bold below in Table 1), but not for the long serve condition. The analysis therefore only examined the short serve and found experts favoured the arm and shoulder for refixations, the elbow, shoulder, head, belly and legs for first visual intake durations and the shuttle, shoulder, head, belly and legs for dwell times. Overall, the shoulder was the only AOI found to show a significant main effect across all measurements.

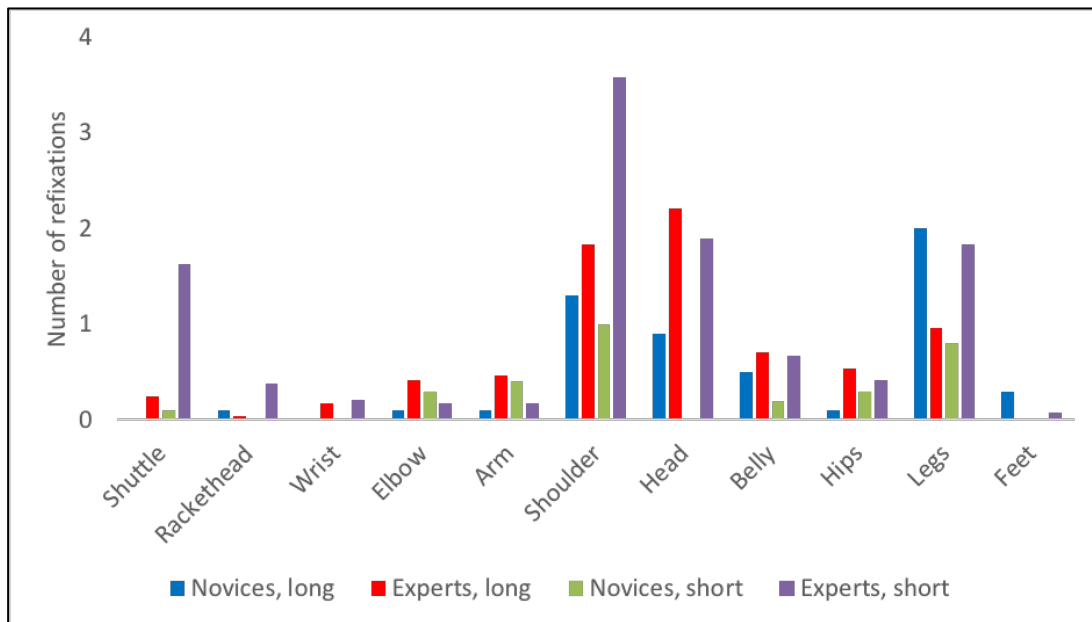


Figure 2. The mean number of refixations for novices (shown in blue for the long serve and green for the short serve) and experts (shown in red for the long serve and purple for the short serve, for the 11 AOI).

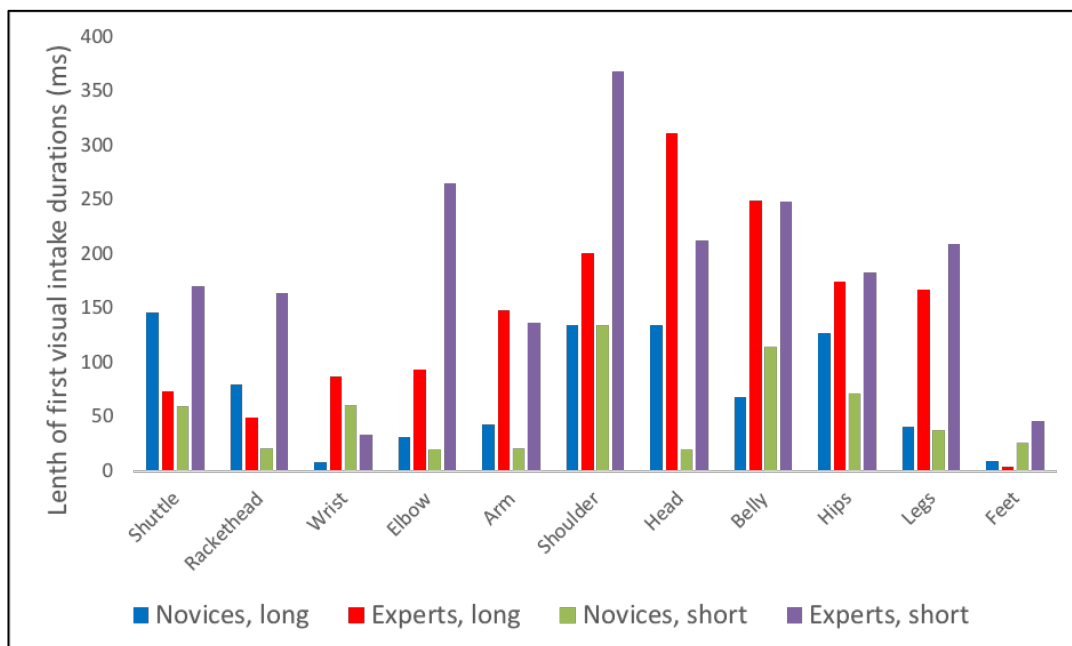


Figure 3. The mean values of first visual intake duration for novices (shown in blue for the long serve and green for the short serve) and experts (shown in red for the long serve and purple for the short serve, for the 11 AOI).

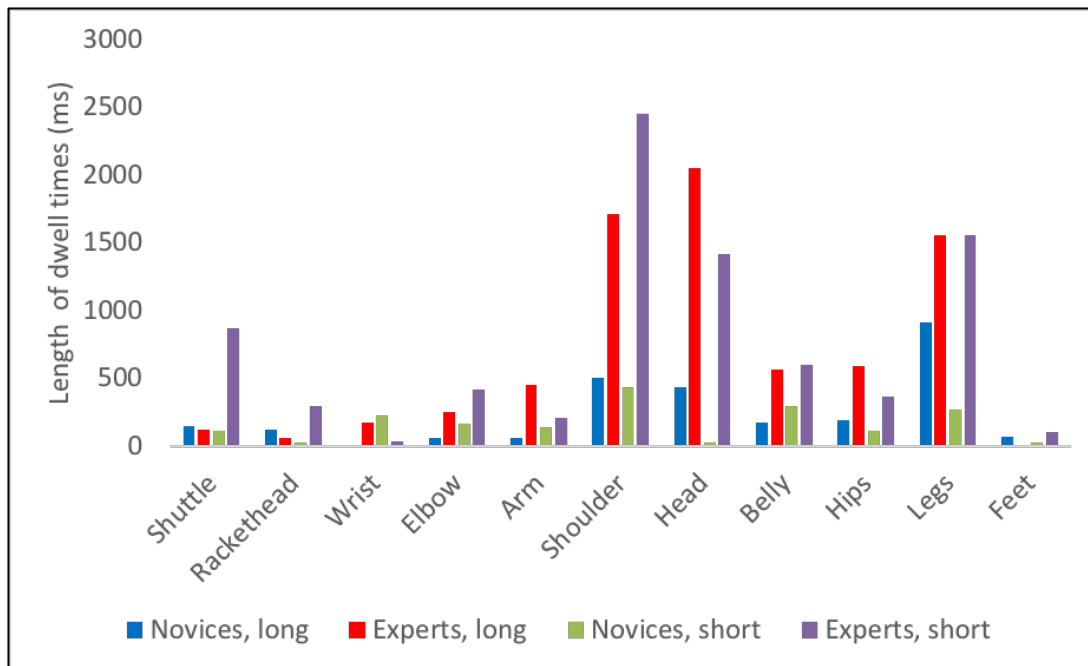


Figure 4. The mean values of dwell time for novices (shown in blue for the long serve and green for the short serve) and experts (shown in red for the long serve and purple for the short serve, for the 11 AOI).

Table 1.

The Mann-Whitney *U* test values and significance levels for refixations, first visual intake duration and dwell time between levels of expertise for the short serve condition.

AOI	Refixations	First visual intake duration	Dwell time
Shuttle	$U=79.00, p>0.05$	$U=68.50, p>0.07$	<b><math>U=60.00, p&lt;0.03</math></b>
Racket	$U=100.00, p>0.05$	$U=69.00, p>0.07$	$U=67.00, p>0.06$
Wrist	$U=115.00, p>0.73$	$U=104.00, p>0.69$	$U=102.00, p>0.63$
Elbow	$U=124.00, p>0.99$	<b><math>U=60.00, p&lt;0.03</math></b>	$U=71.00, p>0.09$
Arm	<b><math>U=124.00, p&lt;0.03</math></b>	$U=85.50, p>0.25$	$U=109.50, p>0.83$
Shoulder	<b><math>U=65.00, p&lt;0.03</math></b>	<b><math>U=47.00, p&lt;0.01</math></b>	<b><math>U=43.00, p&lt;0.01</math></b>
Head	$U=90.00, p>0.21$	<b><math>U=63.50, p&lt;0.04</math></b>	<b><math>U=60.00, p&lt;0.03</math></b>
Belly	$U=98.50, p>0.34$	<b><math>U=62.50, p&lt;0.04</math></b>	<b><math>U=63.50, p&lt;0.04</math></b>
Hips	$U=119.50, p>0.34$	$U=94.00, p>0.43$	$U=92.50, p>0.38$
Legs	$U=94.00, p>0.27$	<b><math>U=64.50, p&lt;0.05</math></b>	<b><math>U=64.50, p&lt;0.05</math></b>
Feet	$U=120.00, p>0.87$	$U=103.00, p>0.66$	$U=102.00, p>0.63$

## Part 2

To further understand the use of gaze during return of badminton single serves, the 11 AOI were grouped into three general sites; upper body, lower body and areas away from the opponent's body. The mean values formed by the experts and novices during refixations, first visual intake durations and dwell times were computed. The mean values for refixations (Figure 5), first visual intake durations (Figure 6) and dwell time (Figure 7) all indicate higher mean values for the experts compared to the novices. The only exceptions are found in the long serve condition. For refixations, the exception is found for the AOI located on the lower body and, for the first visual intake durations the exception is AOI located on the away from the body. Both experts and novices showed higher mean values for the upper body during both the long serve condition

and the short serve condition (see Figure 5, Figure 6 and Figure 7).

The Shapiro-Wilk's test found data to be both normally and non-normally distributed so the Mann-Whitney U test was used to test for differences between experts and novices. For refixations, the Mann-Whitney U test revealed a significant main effect for around the body ( $U=431.00, p<0.05$ ), but was non-significant for either the upper body ( $U=551.00, p>0.05$ ) nor lower body ( $U=501.50, p>0.05$ ). For first visual intake durations, the test was non-significant for the around the body ( $U=408.50, p>0.05$ ), the upper body ( $U=515.00, p>0.05$ ) and the lower body ( $U=496.50, p>0.05$ ). Lastly, for dwell time, a significant main effect was discovered for around the body ( $U=382.00, p<0.05$ ), but not for either the upper body ( $U=539.50, p>0.05$ ) nor lower body ( $U=503.50, p>0.05$ ).

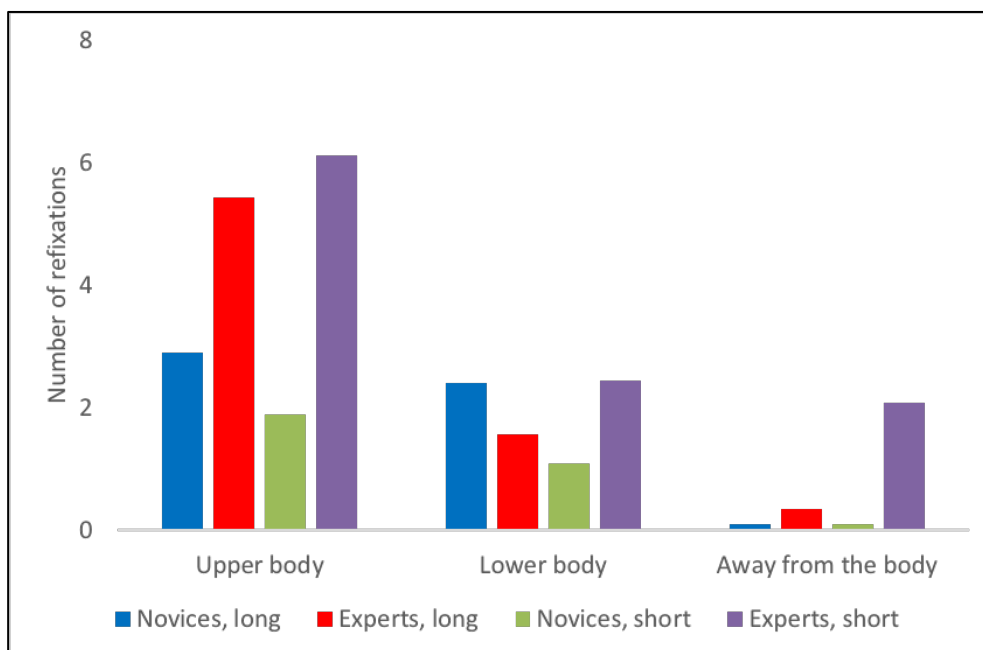


Figure 5. The mean values of refixations for novices (shown in blue for the long serve and green for the short serve) and experts (shown in red for the long serve and purple for the short serve, for the three AOI).

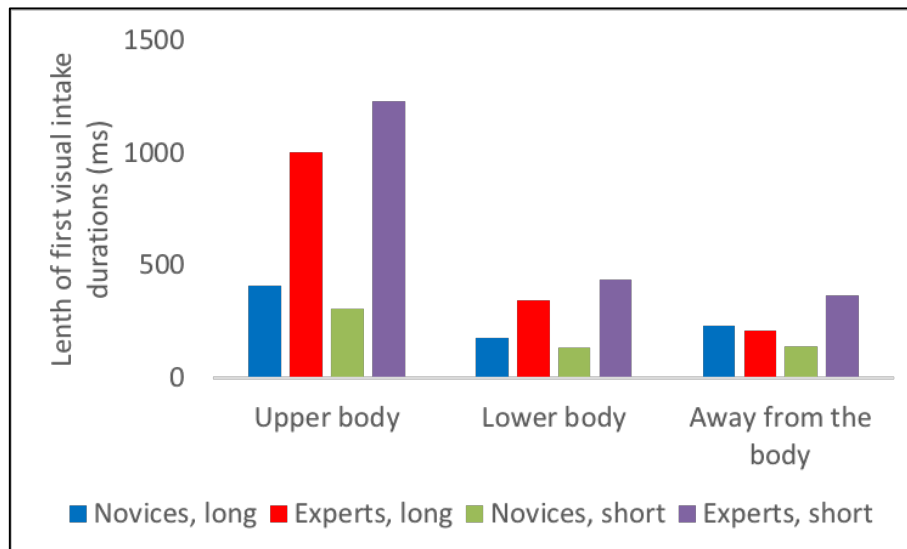


Figure 6. The mean values of first visual intake duration for novices (shown in blue for the long serve and green for the short serve) and experts (shown in red for the long serve and purple for the short serve, for the three AOI).

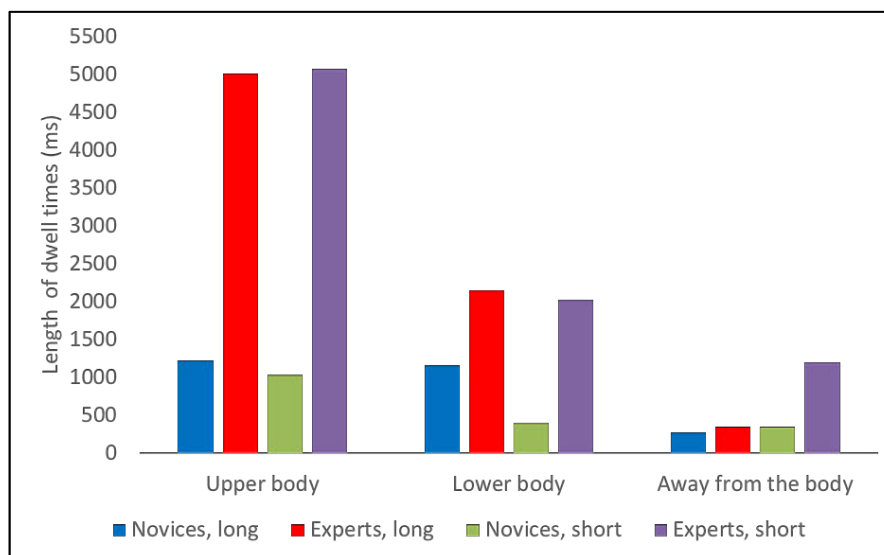


Figure 7. The mean values of dwell time for novices (shown in blue for the long serve and green for the short serve) and experts (shown in red for the long serve and purple for the short serve, for the three AOI).

## Discussion

To our knowledge, this is the first study to investigate eye movement patterns in badminton singles players during the returns of forehand serves in real-life situations. The study sought to investigate the development of fixation sites during serve retrieval without asking the participants to look at

specific points. It was recognised that naturalistic behaviours would be compromised by asking participants to focus on points and thus eliminate the real-life aspect of the study. The analysis assumes that the more often participants returns to an AOI (refixations), and the longer they spend looking at the AOI (first visual intake and dwell time), the more important that AOI is for correct serve returns.

Badminton players may use information provided from the environment to their advantages during matches. The studies by Abernethy and Zawi (2007) revealed that experts use the racket and lower body of the opponent in anticipating the direction of a shuttle whereas the novices are inclined to use the arm of the opponent. Our current study supports this statement through the analysis of the 11 AOI. Alder et al. (2014) further found that the experts favoured fixations on the racket and the novices favoured fixations on the wrist. These results were not replicated in this study, possibly due to only comparing results on correct trials. Further research may consider comparing eye movement patterns completed during correct serve returns to those completed during incorrect serve returns. The final relevant badminton study is that of Chia et al. (2017). Their results found that expertise lead to longer preparation stages and more fixations. The longer preparation stage might be needed to complete a technically correct serve or a serve that will throw the opponent off their game. This is also the only opportunity athletes have time to slow down and breathe. Hence the badminton players may take longer preparation stages due to the experienced pressure from the opponent or due to tiredness and the need for a break.

It was hypothesised that experts would score higher on refixations, first visual intake durations and dwell time because of their level of expertise and ability to respond quickly. It was also expected that the data would replicate the findings of previous studies showing that experts would favour AOI on the lower body. The results support the hypotheses that experts make more refixations and longer fixation durations. However, the eye movement patterns for both types of serves demonstrate skill related differences in eye movement strategy with experts paying more attention to salient features on the upper body of the opponent.

Abernethy and Zawi (2007) proposed from their findings that experts form AOI towards the racket and lower body of the opponent. In support, both experts and novices were found to fixate on the racket and lower body but our study found that

badminton players made fixations on other places as well.

It is foreseeable that the badminton players, regardless of experience, may display fixation patterns towards the 11 AOI due to the physical actions taking place during a serve. Simply put, a right-handed dominant badminton player will serve holding the racket in the right hand and the shuttle in the left hand in front of them. The original serve position is produced by standing sideways with the left arm opposite the net, placing the feet on the ground with the weight onto the left foot, which is stood in front of the right foot as if it had taken a small step forward. The racket or shuttle cannot be held above the level of the hips of the player. The player will start the serve cycle by moving the right *shoulder, elbow* and *arm* forwards, in sync with the right *hip* and turning the *belly* towards the net (as commonly seen in other striking sports as well, such as golf). The player will then shift the position of their *legs* by moving their weight from the left leg onto the right leg, i.e. the right *foot* takes a step forward. The cycle ends with the flick of the *wrist* and the *racket* when finally hitting the *shuttle* and placing all the weight from the left foot onto the right dominant foot. All of this takes place in a quick smooth motion. It can be reasoned that it is the movement of the arm that provides the most information towards whether the serve will be a long or a short serve. A long serve requires more of a swing-like motion created by the arm and a short serve is recognised with a more distinct wrist flicking action and less of the arm swing.

Experienced servers will try to deceive their opponents by inhibiting these cues and thereby hiding their intentions for either a long or a short serve from their opponent. However experienced serve returners may also use this knowledge to anticipate the intentions of the opponent and therefore strategically make more and longer fixation sites towards these areas in correctly anticipating which serve is about to take place. This prediction is supported by our study which found significantly greater dwell times on the shuttle, the elbow, the shoulder, the head, the belly and the legs (see Figure

4). Future studies investigating the relationship between successful and non-successful serve returns may further explain the importance of fixating on specific locations.

The long serve may be easier to anticipate than the short serve because it requires a bigger action than the short serve. This is supported by the data showing that experts made more fixations and longer fixation durations for the short serve than the long serve, i.e. experts make more fixations to validate the correct serve taking place. Furthermore, the data found very small variations in the average of fixations made by the novices for the different locations for the long and the short serve, indicating their inexperience and thereby supporting the notion that experts fixate in a more discriminating manner as a result of their greater anticipation.

The strength of the study remains its naturalistic design. We were able to extract reliable eye tracking data by exposing the participants to an environment that resembles natural match situations. Overall, the results are found to support the hypotheses: the experts, in comparison to the novices, showed higher scores of refixations and longer fixation durations. Future studies should therefore aim to continue the development of real-life investigations to further the literature and the understanding on the use of eye movements during badminton.

## Conclusion

Badminton players use fixation sites when responding to countermoves from their opponent and some of these fixation sites have been found to be of more importance than others. The fixation sites considered in this study are located on the shuttle, racket, wrist, elbow, arm, shoulder, head, belly, hips, legs and the feet of the opponent. Experts have been found to complete different eye movement patterns in comparison to novices, suggesting that expertise influences the pattern of eye movements in relation to anticipation skills taking place in badminton.

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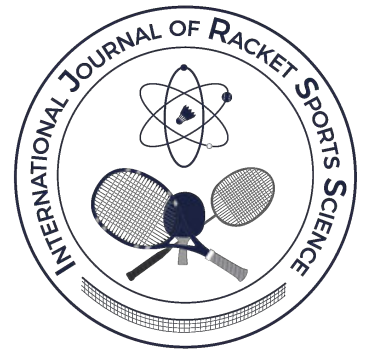
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# Influence of sport-practice-hours on burnout and coping in table tennis players

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## Abstract

The aim of this research was to analyse burnout (estimated by emotional and physical exhaustion) and coping (as estimated by the need to seek support) in relation to the number of sport-practice-hours undertaken by table tennis players of various levels of success. A sample of 180 Spanish table tennis players (mean age = 33.87 years; SD = 16.64; 149 men and 31 women) voluntarily participated in the study and filled out a series of self-report questionnaires. The results revealed that there was a significant difference among table tennis players on emotional and physical exhaustion ( $p < 0.01$ ) with players who practiced more than ten hours reporting higher levels of emotional and physical exhaustion. There was a significant difference in coping behaviour ( $p < 0.01$ ) with players who practiced more than 10 hours reporting the greatest need. Finally, players who played at a higher level (nationally or internationally) had a greater number of hours of training. It is concluded that players and coaches should take account of the time spent in sport-practice should because it can increase burnout levels in table tennis players. Moreover, coping skills could be influenced by sport-practice-hours, but further research should clarify these outcomes.

Keywords: *Burnout, Coping, Training, Mental Skills, Players*

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## Introduction

Table tennis is a sport in which coping and burnout play a crucial role in sport career of players (Kurimay, Pope-Rhodus, & Kondric, 2017; Martinent, Gareau, Lienhart, Nicaise, & Guillet-Descas, 2018; Martinent, Nicolas, Gaudreau, & Campo, 2013). Both variables can modify performance and can change the way that players perceive their execution (Chen, Chang, Hung, Chen, & Hung, 2010). Coping is conceptualised as a set of cognitive and behavioral strategies that can modify player's perception regarding internal and/or external threats, evaluated as exceeding their perceived resources (Lazarus & Folkman, 1984). The coping theorists (Gaudreau & Blondin, 2002; Nicolas, Gaudreau, & Franche, 2011) pointed out that there are three coping dimensions in the context of sport competitions: Task-oriented coping (strategies to face directly the stressful situation) such as logical analysis, imagery/thought control or social support; Disengagement-oriented coping (strategies related with withdraw desire from the process of actively striving towards an stressful situation) such as resignation or venting emotions; And distraction-oriented coping (strategies used to momentarily focus the attention on external and internal stimuli unrelated to the stressful situation) such as distancing or mental distraction. In the field of other sports, Doron and Martinent (2016) proved that task-oriented coping was related with challenge appraisal, positive emotions and performance, meanwhile, disengagement-oriented coping was linked with threat appraisal and negative emotions. In a table tennis study, Martinent and Decret (2015) highlighted among players that task-oriented-coping strategies (strategies focused on task requirements to solve a problem) were shown to be the best coping strategies in relation to stress, burnout and recovery. Therefore, task-oriented coping has shown to be the best way to handle coping in sport in general and in table tennis in particular.

Burnout is one of the most important variables in dropout of table tennis players (Martinent, Louvet & Decret, 2016) and this variable has shown a relationship with a bulk of negative sport outcomes, such as drop out, decreased performance, lack of

enthusiasm, loss of social cohesion or depressive symptoms (Fletcher, Hanton, & Wagstaff, 2012; Martinent et al., 2018; Nicholls & Polman, 2007). Burnout is the feeling of an emotional syndrome characterized by emotional and physical exhaustion, sport devaluation and reduced sense of accomplishment (Raedeke & Smith, 2001). Moreover, burnout can lead to negative emotions among table tennis players and to poor performance, increasing the risk of withdraw symptoms (Martinent et al., 2018). Even, burnout symptoms can be increased from the beginning of the season to the final competitions and a minimum amount of time is needed to reduce again these levels, despite finishing of training and competitions (Martinent et al., 2016). Also, the engagement level of the players that are in training settings or in professional clubs can result in turn in an increase of burnout levels rather than more amateur players (Martinent, & Decret, 2015). Thus, the degree of engagement and the spent hours in table tennis can be an issue to consider in burnout in players.

Several researchers have shown that sport-practice-hours are related to the attainment of better performance in terms of technical and physical skills (Elferink-Gemser & Vissche, 2012; Ericsson, 1996; Ericsson, Krampe, & Tesch-Römer, 1993; Ford, Coughlan, Hodges, & Williams, 2016). In particular, researchers that follow the theory of deliberate practice highlighted the positive outcomes in sport performance of those that spend more training hours (Ericsson, 1996; Ericsson et al., 1993). Regarding that theory, it stands out that there is a minimal number of hours in order to get a high sport performance level (Elferink-Gemser & Vissche, 2012; Ericsson, 1996; Ericsson et al., 1993; Ford et al., 2016; Hendry, Crocker, Williams, & Hodges, 2019).

Not only can the sport-practice-hours lead to a better performance, but it is also important to take into account their potential effects on a wide variety of outcomes such as motivation, concentration or enjoyment (Campinelli & Gobet, 2011; Casado, Ruiz-Pérez, & Graupera, 2014; Hambrick, Oswald, Altmann, Meinz, Gobet, & Campitelli, 2013). Casado, Ruiz-Pérez, & Graupera (2014) pointed out that the best athletes in terms of sport performance can

practice with more concentration, effort and enjoyment. Consequently, sport-practice-hours is a variable that should be considered in the influence of mental performance in table tennis players. Moreover, as a novelty of this work, practice-hours will be considered as a variable that can modify burnout and also the coping strategy employed by a player in competition. To date, no previous studies have examined the relationship between these variables in table tennis players, even though, knowing that the amount of practice hours is quite demanding in table tennis players.

To sum up, previous studies did not highlight the influence of sport-practice-hours in coping and burnout in table tennis, two important influences on table tennis players' performance which can be influenced by sport-practice-hours (Martinent et al., 2013; Martinent et al., 2018). In line with that, it is noteworthy to mention that this study can shed light for future research opening a new field of development on the way to control burnout and coping and how they are influenced by the sport-practice hours. Moreover, the importance of sport practice-hours to reach success in sporting context has been proved by far in previous works (Campinelli & Gobet, 2011; Casado et al., 2014; Hambrick et al., 2013). Therefore, the aim of this research was to analyse if there were differences in coping and burnout depending on sport practice hours. An hypothesis was established that: the more hours that players practice, the higher will be the burnout symptoms and coping needs.

## Methods

### *Participants*

A sample of 180 Spanish table tennis players (mean age = 33.87 years; SD = 16.64; 149 men and 31 women) voluntarily participated in the study. The majority were amateur ( $n = 144$ ) and a minority were professionals ( $n = 36$ ). Furthermore, 165 were federated players and 15 were not associated to federations. Concerning the achievements, 155 reached local success, 137 reached regional success, 78 reached national success and 24 reached international success. Regarding the time of sport practice, 65

players practiced between 0 and 5 hours per week, 71 players practiced between 5 and 10 hours per week, 44 players practiced more than 10 hours per week.

In order to maximise the external validity and generalisability of the study, participants were collected from all around Spain. Hence, the study followed a cross-sectional design.

### *Variables and instruments*

Sociodemographic questionnaire. To measure the sociodemographic variables: gender, age, federated, professional/amateur, successes (local, regional, national and international) and training hours; an *ad hoc* questionnaire with 9 questions was made. The questions were dichotomous in case of: gender (male/female), local/national/regional/international successes (Yes/No), federated (Yes/No), professional; a polytomous in case of practice hours (from 0-5 hours/ from 5 to 10 hours/ more than 10 hours); and one open question for age. Most of the questions were closed-ended in order to be responded to easily.

The Spanish version (Molinero, Salguero, & Márquez, 2010) of the Coping Inventory for Competitive Sport (CICS; Gaudreau & Blondin, 2002) was comprised of 31 items and respondents used a 5-points Likert type scale ranging from 1 (nothing) to 5 (much). It contains 8 factors with the following Cronbach Alpha: resignation (4 items;  $\alpha = .77$ ), relaxation (4 items;  $\alpha = .82$ ), distancing (3 items;  $\alpha = .51$ ), logical analysis (7 items;  $\alpha = .67$ ), seeking support (2 items;  $\alpha = .77$ ), imagery/thought control (5 items;  $\alpha = .73$ ), venting emotions (3 items;  $\alpha = .83$ ) and mental distraction (3 items;  $\alpha = .77$ ).

The Spanish version (Arce, De Francisco, Andrade, Seoane, & Raedeke, 2012) of the Athlete Burnout Questionnaire (ABQ; Raedeke & Smith, 2001) is made up of three subscales measuring emotional/ physical exhaustion, sport devaluation, and reduced feeling of accomplishment. The scale has 15 items for each dimension with five response options (from 1- almost never to 5 - almost ever). The Cronbach alphas in the present study were .88 for emotional/physical exhaustion, .64 for reduced accomplishment and .67 for sport devaluation.

The Oviedo scale of infrequency response (INF-OV; Fonseca-Pedrero, Lemos-Giráldez, Paino, Villazón-García, & Muñiz, 2009) was used to minimize acquiescence and dishonest participants. This is a 12-item self-report measure with a 5-point Likert-type rating scale format (1 totally disagree; 5 totally agree). Its goal is to detect participants who responded randomly, pseudo-randomly or dishonestly on self-reports (e.g., “The distance between Madrid and Barcelona is greater than between Madrid and New York”). The participants with more than 4 incorrect answers were deleted from the sample. In this study, 10 participants were taken out of the sample.

### Procedure

The study followed the international ethical guidelines and anonymity was preserved. Firstly, researchers contacted the Spanish Table Tennis Federation to announce the possibility to participate in the study. Once, the Spanish Federation approved the announcement, they publicised it on their website. Regarding that, the interested players contacted the main researcher and once they claimed their interest in participating, they received the link to access the questionnaire. After participants accessed to the questionnaire (it took 20 min), they signed an informed consent, then, they began to complete the research survey. The data was hosted on the application "Google Drive."

### Data Analysis

The data analysis was performed using SPSS 19 version software. The descriptive analysis of average, minimum, maximum, frequencies, percentage and standard deviation were used to describe the sample characteristics. A bivariate correlation was conducted to ensure that there was not collinearity in the study variables. The MANOVA analyses were performed to examine the differences among the variables (Burnout and Coping) across groups of sport-practice-hours. A significant multivariate effect ( $p < .05$ ) was followed by subsequent ANOVAs using post hoc comparisons (Tukey HSD) of group means with Bonferroni adjustment (which means that the significance ( $p < .05$ ) should be divided by the number of cases) to prevent

Type I error. Also, Partial eta squared ( $\eta^2$ ) was assessed for providing an index of effect size. Finally, a series of chi-square tests was computed to examine if there were significant relationships between groups of sport-practice-hours and gender.

## Results

Table 1 shows the descriptive statistics and bivariate correlations between the study variables. Regarding coping, results revealed: (a) high scores of: Relaxation, Logical Analysis and Thought Control; Medium scores of: (b) Resignation, Distancing, Seeking for Support, Venting Emotions and Mental Distraction. Relating to Burnout, participants reported: (a) medium levels of: Physical and Emotional Exhaustion, Reduce Sense of Accomplishment and Sport Devaluation. The correlations among the study variables did not indicate multicollinearity, as they ranged from  $-.23$  to  $.57$  (i.e., confidence intervals ( $\pm$  two standard errors) for all the correlations supported the discriminant validity insofar as none of the intervals included 1.0).

Secondly, to know if players belonging to distinct groups of sport-practice-hours reported significantly different scores of coping and burnout a MANOVA analysis was performed (Lambda de Wilks =  $.62$ ;  $F = 1.99(42)$ ;  $gl = 314$ ;  $p < .01$ ;  $Eta^2 = .21$ ). The results (Table 1) revealed that there were differences among table tennis players from distinct groups of sport-practice-hours on emotional and physical exhaustion ( $p < .01$ ). In particular, table tennis players that practiced more than 10 hours reported significantly higher levels of emotional and physical exhaustion than the group that practiced less than 5 hours of training. Results of *post hoc* comparison (Tukey HSD) are presented in Table 2.

Concerning coping strategies, the results (Table 3) showed statistically significant differences in seeking for support ( $p < .01$ ). In particular, table tennis players that practice more than 10 hours reported the highest levels of seeking for social support, showing the Tuckey analysis that were differences between the group that practiced “more than 10 hours” and the group “from 5 to 10 hours”. Results of post hoc comparison (Tukey HSD) are presented in Table 3.

Finally, the results of chi-square tests showed that the distribution of gender ( $\chi^2 = .55$ ;  $p > .05$ ) or federated players ( $\chi^2 = 3.90$ ;  $p > .05$ ) was not significantly different across the three groups of sport-practice-hours). However, national successes ( $\chi^2 = 6.04$ ;  $p < .05$ ), and international successes ( $\chi^2 = 6.87$ ;  $p < .05$ ) significantly differed across the three groups

of sport-practice-hours. As can be expected, the more successful the players are (nationally or internationally), the more hours of training the players had.

Table 1.

*Descriptive statistics and correlations among the variables.*

	1	2	3	4	5	6	7	8	9	10	11
1.Resignation											
2.Relaxation	-0.15*										
3.Distancing	0.29**	0.25**									
4.Logical Analysis	-0.23**	0.55**	0.27**								
5.Seeking for Support	-0.08	0.48**	0.13	0.34**							
6. Thought Control	-0.23**	0.55**	0.18*	0.57**	0.35**						
7. Venting Emotions	0.43**	-0.01	0.33**	0.09	0.19**	0.08					
8. Mental Distraction	0.40**	0.19**	0.32**	0.14	0.21**	0.22**	0.38**				
9. Physical and Emotional Exhaustion	0.36**	-0.04	0.20**	0.02	0.07	0.04	0.39**	0.28**			
10. Reduce Sense of Accomplishment	0.41**	-0.13	0.10	-0.17*	-0.13	-0.20**	0.26**	0.12	0.20**		
11. Sport Devaluation	0.33**	-0.12	0.18*	-0.15*	-0.13	-0.08	0.21**	0.21**	0.17*	0.44**	
Mean	7.92	13.60	6.93	25.10	6.96	18.05	8.22	6.66	11.96	12.36	10.63
Standard Deviation	3.09	3.25	2.23	3.92	1.98	3.33	2.88	2.55	4.37	3.39	3.87
Skewness	.83	-.12	.36	-.24	-.48	-.35	.21	.81	.39	.36	.57
Kurtosis	.57	-.21	-.19	.31	-.05	-.06	-.60	.75	-.24	.24	-.13

Note.  $p < .05^*$ ;  $p < .01^{**}$

Table 2.

*Sport-practice-hours and burnout*

Variables	(a) Less than 5 hours of training (n=65)	(b) From 5 hours to 10 hours of training (n=71)	(c) More than 10 hours of training (n=44)	F (p)	Eta <sub>2</sub>	Tuckey
Emotional/ Physical Exhaustion	10.81 (3.89)	12 (4.63)	13.59 (4.17)	5.56 (.00)*	.05	c>a
Reduced Accomplishment	12.63 (2.98)	12.59 (3.34)	11.61 (3.96)	1.44 (.23)	.01	-
Sport Devaluation	11.76 (3.55)	10.52 (3.90)	9.15 (3.81)	6.38 (.01)	.06	-

Note. \* $p < .016$  (after Bonferroni adjustment)

Table 3.

*Sport-practice-hours and coping*

Variables	(a) Less than 5 hours of training (n=65)	(b) From 5 hours to 10 hours of training (n=71)	(c) More than 10 hours of training (n=44)	F (p)	Eta <sup>2</sup>	Tuckey
Resignation	7.70 (3.07)	8.26 (3.25)	7.70 (2.88)	.70 (.49)	.01	-
Relaxation	13.23 (3.21)	13.70 (3.48)	13.97 (2.92)	.74 (.47)	.01	-
Distancing	6.89 (2.05)	6.76 (2.26)	7.29 (2.43)	.80 (.45)	.01	-
Logical Analysis	24.63 (3.81)	24.71 (4.14)	26.43 (3.48)	3.42 (.03)	.03	-
Seeking Support	6.78 (1.84)	6.69 (2.09)	7.68 (1.86)	3.94 (.00)*	.04	c>b
Imagery/ Thought Control	17.84 (3.16)	17.98 (3.83)	18.47 (2.66)	.49 (.61)	.01	-
Venting Emotions	7.73 (2.86)	8.28 (2.84)	8.84 (2.93)	1.95 (.14)	.02	-
Mental Distraction	6.44 (2.44)	7.01 (2.94)	6.43 (1.95)	1.08 (.34)	.01	-

Note. \* $p < .006$  (after Bonferroni adjustment)

## Discussion

The aim of this research was to analyse if there were differences in coping and burnout depending on

sport-practice-hours. Results showed that table tennis players that practice more than ten hours reported the highest levels of emotional and physical exhaustion and also significant differences with the group that practice less than 5 hours. Furthermore,

repetitive tasks can increase burnout syndrome (Demerouti, Bakker, Nachreiner, & Ebbinghaus, 2002). Hence, table tennis players that spend more than ten hours training may be more at risk to experience burnout symptoms. Moreover, significant relationships were found between (national and international) success and number of hours of training. It is not surprising that national and international success players were the one that practice more hours throughout the sample. Consequently, an increase of training hours as well as more success in table tennis players could be linked with greater burnout symptoms.

On the other hand, results showed statistically significant differences in seeking support, in which table tennis players who practice more than ten hours reached the highest levels. These results could be explained because a greater number of training hours can lead to burnout symptoms and in turn need the support (Demerouti et al., 2002; De Orleans, Reis, & Andrade, 2018). Consequently, an increasing number of hours could not improve coping, due to the higher levels of demands that can lead to burnout.

Nevertheless, it is difficult to explain why coping levels are similar between high hours training players (more than ten hours) and low hours training players (less than five hours). Perhaps a minimal amount of training hours is not needed for a greater use of coping strategies in table tennis, following the critics of the deliberate practice theory (Campinelli & Gobet, 2011; Casado et al., 2014; Hambrick et al., 2013). It is also important to keep in mind that in the present study, we assessed the use of coping strategies and not the effectiveness of such coping strategies. In addition, table tennis players that only practice less than five hours do not have a high competition level and they do not require the use of salient coping strategies (De Orleans et al., 2018). As a whole, more research is needed to explain such surprising results regarding coping.

As for limitations of the study, it should be considered that the relatively low number of women in the sample makes comparisons among gender difficult. Another limitation is that this study was

only conducted with Spanish table tennis players. Thus, cultural differences could have influenced the results of the present study.

As for future proposal lines, it would be quite interesting to analyse other variables that could be linked to sport-practice-hours, because the levels of coping were so similar among less than five hours group and more than ten hours group. For example, coaching leadership or team cohesion could be explored in future studies. Moreover, it could also be investigated what are the number of hours that exceed emotional and physical exhaustion levels. This would help coaches to control training loads in order to prevent emotional and physical exhaustion.

As a conclusion, the time of sport-practice-hours should be considered as a variable that might modify mental performance, because it could increase burnout levels in table tennis players. Moreover, coaches should take it into account in order to prevent the prevalence of burnout symptoms among the players practicing the most hours of training per week. Coping could also be influenced by sport-practice-hours even if the pattern of results of the present study is ambiguous regarding this issue. In particular, it is needed to clarify why coping outcomes are similar among the highest practice hours group and the lowest practice hours group. Therefore, future research is needed to clarify the optimal number of hours in terms of mental skills.

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# A tennis field test to objectively measure the hitting accuracy based on an Excel spreadsheet: Practical guidelines and applications

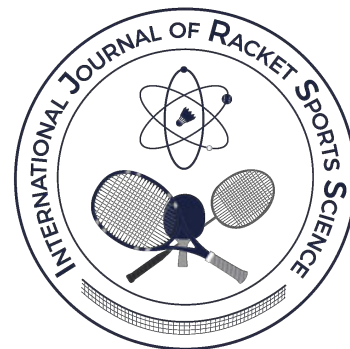
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## Abstract

Stroke accuracy is highly related with tennis performance and has traditionally been quantified using general areas of scoring. Hence there is a need to develop methods that allow accuracy to be measured with higher resolution. The aim of the work is to develop a field test and an Excel spreadsheet associated that allows to evaluate the accuracy of the strokes with a resolution up to centimetres and to study how shots landings are distributed. The test consists of 4 series of 20 groundstrokes performed in the down the line or cross-court direction (this is modifiable). The 2D coordinates of bounce of the ball is recorded with a camera, digitalized using a specialized software and introduced in the Excel spreadsheet. Then it computes a series of parameters that describe the 95% confidence ellipse of the shot landing on the court. A real example of the test outcomes of two advanced players - performing forehands and backhands down the line- is shown. Consistent with previous literature both players obtained a better accuracy in the mediolateral direction than in the longitudinal direction and ellipses were oriented almost parallel to the sideline (ellipse tilts were below 12 degrees in all cases). Ellipse area was considerably greater for the backhand than for the forehand in player two (38.8 vs. 55.5 m<sup>2</sup>) but not in player one (51.5 vs. 50.8 m<sup>2</sup>). Finally, the centre location of the ellipse in the longitudinal axis was positive in all cases (near 200 cm) which suggest that both players preferred to make short shots rather than send the ball out of the limits of the baseline. We conclude that this methodology can be used by researchers that want to assess accuracy with high resolution and by coaches that want to evaluate -with high sensibility- the player progression after a training program.

Keywords: *Tennis, Stroke Precision, Testing, Racket Sports, Software*

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## Introduction

Tennis performance depends, among other factors, on tennis hitting accuracy (Landlinger, Stöggel, Lindinger, Wagner, & Müller 2012). There is an extended bibliography that shows specific tennis field tests for measuring it, but most of those tests establish a categorical system of punctuations based on landing areas (Baiget, Fernández-Fernández, Iglesias, Vallejo, & Rodríguez, 2014; Davey, Thorpe, & Williams, 2003; Smekal et al., 2000; Strecker, Foster, & Pascoe, 2011). Generally, in most of those tests a ball that hits the corner of the court has a higher score than a ball that lands in the middle. They are limited and for example cannot differentiate between a ball that touches the line and a ball that lands out by a minimal distance. There are a few specific tennis field protocols that have been used to evaluate the accuracy in strokes with centimetre accuracy (Delgado-García et al., 2019; Landlinger et al., 2012; Vergauwen, Spaepen, Lefevre & Hespel, 1998; Yamamoto, Shinya, & Kudo, 2018). They have been used to: compare the accuracy of strokes based on the direction of the strokes and level of the player (Landlinger et al., 2012); compare the accuracy depending on the type of stroke (Delgado-García et al., 2019; Landlinger et al., 2012); analyse the effect of fatigue on accuracy (Vergauwen, Lieven, Brouns, Fred, & Hespel, 1998) or relate the accuracy with cognitive aspects (Yamamoto et al., 2018). Despite these tests, little information is available on how to evaluate accuracy in the particular case of tennis. There is still a need to develop tools and methodologies that allow trainers and scientists to assess accuracy with sufficiently high resolution.

The development of new technologies applied to sport is still on a rise. Although there are affordable devices to measure the speed of hitting (speed radars and inertial sensors), there are not many instruments to measure the accuracy of ball placement. There are some expensive systems that provide tennis match analytics such as the Hawk-eye (Hawk-Eye Innovations, 2016) or the smart tennis courts mounted by the company PlaySight (PlaySight Interactive, Ltd., Kokhav Ya'ir, Israel). The Hawk-eye is used during high level tournaments and the data that provide have

been used in different research works (Reid, Morgan, & Whiteside, 2016; Wei, Lucey, Morgan, & Sridharan, 2013). Other solutions are shown in the scientific bibliography such as the proposed by Messelodi, Modena, Ropele, Marcon & Sgrò (2019) or Wawrzyniak & Kowalski (2016). However, there are hardly any low-cost and ease of use technologies that have a similar purpose to these systems. In this regard, we could mention the Swing Vision tennis app for iOS (Mangolytics Inc., 2019), based on artificial intelligence. Another tool a little more expensive is Mojjo, that uses two simple mobile phone cameras (Mojjo, 2019, Paris, France). It is also interesting to mention the "In / Out" device, a double camera that is placed on the net and that performs a mapping of the location of the ball landing on the court (according to the manufacturers it has millimetre accuracy). Furthermore, there is specialized software that allows digitisation the ball landing location (e.g., Kinovea, Tracker, SkillSpector, Check2D) and therefore study its accuracy. Relevant ball trajectory data can be obtained with this software, but it remains difficult to extract parameters related to accuracy. Excel is a software that many scientists and coaches use on a daily basis and that allows semi- or even fully-automated mathematical calculations for sports analysis. For example, Chavda et al. (2018) designed an Excel spreadsheet that serves to analyse force platform data. Another Excel application allows running automated algorithms for biomechanical data analysis such as data filtering, interpolation, differentiation, integration, etc. (Biomechanics Toolbar, Vanrenterghem, 2016). In a recent study (Delgado-García et al., 2019) the distribution of groundstrokes was analysed using confidence ellipses created with a statistical package for Excel which allows to fit a scatter plot with a bivariate normal distribution (Zaiontz, 2015). This kind of distribution has been used in other sport science research, such as in posturography assessments (Schubert & Kirchner, 2014).

Therefore, the objective of this work was to propose a field hitting test based on previous literature and describe an accompanying Excel tool, which allows the calculation of confidence ellipses of a tennis player for the forehand and backhand stroke. This tool can be

used by coaches and scientists who want to objectively and with centimetre resolution assess the accuracy of tennis players. We will show an exemplary usage of the tool with two advanced tennis players.

## Methods

### *Sample*

Two experienced tennis players volunteered to complete a hitting field-test including 80 strokes each ( $n = 160$ ). The two players had more than 20 years of playing experience and an international level number of three which correspond with advanced players (ITF, 2019). For descriptive purposes their body composition was measured with bioimpedance (Inbody 230, Biospace, Korea). Player 1 was 49 years old (mass = 80 kg; skeletal muscle mass = 34.8 kg, body fat percentage = 24% and IMC = 29.2). Player 2 was 33 years old (mass = 74.8 kg; skeletal muscle mass = 36.9 kg, body fat percentage = 13.7% and IMC = 23.3). Both participants were right-handed, used a one-handed backhand and didn't report any musculoskeletal injury that would limit their stroke or shifting technique or the use of drugs due to serious illness. They were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent according to ethical principles for medical research involving human subjects as defined by the Declaration of Helsinki.

### *Procedures*

#### **Set-up of the field tennis test**

The proposed hitting test consists of 4 series of 20 groundstrokes each (80 strokes in total). The evaluator can select four different types of test explained in Table 1. In the example shown in this manuscript the players were told to hit forehand and backhands down the line (test type 1) and to find the centre of the target while maintaining a similar pace to competition pace. The sheet can be used for other types of strokes such as volleys, approach shots, backspin strokes, lobs, etc. The only premise that must be met is that the shots must be made to the right half and left half of the

opposite track alternately. If the test measures the accuracy in terms of proximity to the objective but also considering the number of errors, the initial information provided to the participant must specify it, since this factor can condition the player to take a greater or lesser risk with their strokes and will probably change the test results. For the present study the target was located inside the court at a distance of 1 m from the sideline and the baseline (Figure 2) but the evaluator can select other locations. It is recommended to perform a warm-up of about 8 min (3 min of running and mobility exercises, 3 min of rally with another player and 2 min performing a series of the test). To ensure that fatigue does not affect the results of each series participants should be given 3-5 min rest between them so as to allow their heart rate to return to resting levels or within 10 beats/min of resting levels (Lyons, Al-Nakeeb, Hankey, & Nevill, 2013) which can be assessed with the use of a pulsometer. We recommend the use of a device that has been validated in the scientific bibliography, such as the polar RS400 which has been found valid and reliable during both physical activity and exercise training (Engström et al., 2012).

To ensure that all players perform the test in the same conditions of pace and speed of the ball, a ball throwing machine can be used. For example in the study of Lyons et al. (2013) they use a Tennis Tutor Plus (Sports Tutor, USA) and the speed of release was configured around 70 km/h with a little of topspin so the ball travels over the net at a height of approximately 1.5 m and lands within approximately 2 m of the baseline. For the present study a Lobster Grand Slam IV in the predetermined configuration mode called "Two lines" was used. The throwing rate was of 20 throws per minute and the release speed of 70 km/h. The shot distance to the centre of the court was configured as medium, and the distance to the baseline was configured as row A. Finally, the spin level 1 was selected (from 3 positive levels, being 0 the flat shot and 3 the highest topspin allowed by the machine).

Table 1.

*Possible test settings and order of the strokes depending on the dominant hand of the player*

Configuration	Description	Order of the strokes			
		Right-handed players		Left-handed players	
		1st stroke	2nd stroke	1st stroke	2nd stroke
Test 1	Forehand and backhand alternately in the down the line direction	Down the line forehand	Down the line backhand	Down the line backhand	Down the line forehand
Test 2	Forehand and backhand alternately in the cross-court direction	Cross-court backhand	Cross-court forehand	Cross-court forehand	Cross-court backhand
Test 3	Forehand down the line and forehand cross-court alternately	Down the line forehand	Cross-court forehand	Cross-court forehand	Down the line forehand
Test 4	Backhand cross-court and backhand down the line alternately	Cross-court backhand	Down the line backhand	Down the line backhand	Cross-court backhand

To assign a value to these numbers in a unit understandable to the rest of the members of the scientific community, a small study was conducted in order to determine the estimated location of the bounce of the ball, the spin of the ball in revolution per minute (revs/min) and the height the ball pass over the net, in the selected mode of the throwing machine (“Two lines”). In this studio, the position of the bounces of the balls sent by the machine was recorded using a 60 Hz rear camera (iPhone 6) and digitized in the Kinovea software (a total of 80 balls were digitized: 40 on the right side and 40 to the left side). The coordinates obtained were entered on the Excel spreadsheet that will be explained in this manuscript and the parameters of the confidence ellipses shown in Figure 1 were obtained. The spin of the ball was determined using coloured balls in such a way that it could be visualize the number of turns the ball takes (14 throws were analysed). The ball's departure from the machine was recorded with a camera sampling at 1000 Hz (Sony RX100 IV) and the time it took for the ball to make two turns was counted in Kinovea moving frame by frame. Subsequently, the speed of rotation of the ball in revs/min was calculated. The height of the flight of the ball over the net was calculated by placing the machine at a distance of 1188.5 cm (the distance from the baseline to the net) respect to a vertical wall of 5 m height. The machine shot in such a way that all the balls entered into a rectangle painted on the

wall of 336 cm high by 182.4 cm wide and the impact of the ball on it was recorded at 60 Hz (iPhone 6s) and digitized in Kinovea (a total of 40 impacts were digitized). The results of these tests are shown in Figure 1. It is important to remark that if the user of the spreadsheet would like to perform the test type 3 or 4 (Table 1) the machine should be configured in such a way that all the throws are directed to one side of the court (the player only perform forehands or backhands strokes in this two test).

Alternatively, the ball can be thrown by an expert coach (Delgado-García, Vanrenterghem, Muñoz-García, Molina-Molina, & Soto-Hermoso, 2018), using a metronome and trying to throw all the balls in the same way. It is recommended to throw the ball at a rate of one throw every three seconds (Delgado-García et al., 2019; Lyons et al., 2013).

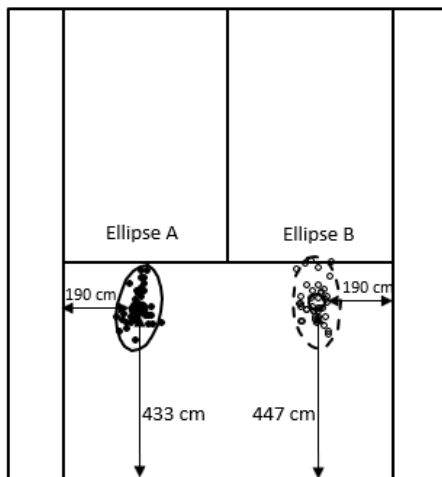


Figure 1. Location of the bounces from the throwing machine Lobster Grand Slam IV in the preconfigured mode “Two Lines”. The figure shows the distance of the centre of the ellipse to the sideline and to the baseline. The ellipse A has a major axis of 108 cm a minor axis of 55 cm and an area of 1.9 m<sup>2</sup>. The ellipse B has a major axis of 118 cm, a minor axis of 59 cm and an area of 2.2 m<sup>2</sup>. The spin of the ball was of  $855 \pm 55$  rpm and the height of the ball over the net was of  $246 \pm 9$  cm.

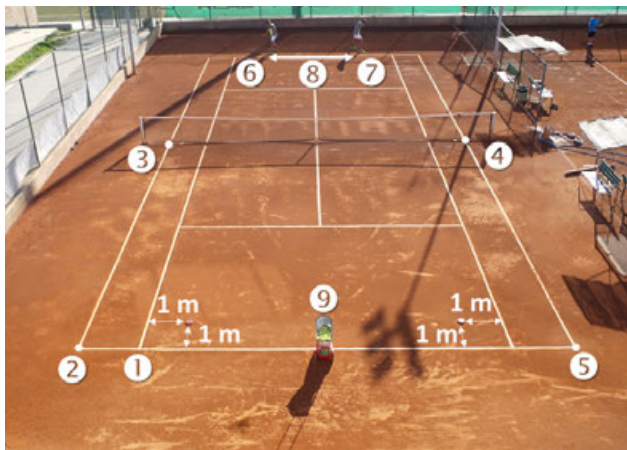


Figure 2. Set-up of the tennis test (view from the camera that records the bounce of the ball) used in this research work. Meaning of the numbers: origin of coordinates (1); corner of the perspective grid in Kinovea (2 to 5); approximate location of 1st stroke (6); approximate location of 2nd stroke (7); displacement of the player (8); ball throwing machine (9).

The test is recorded with a camera placed behind and above the court, so that the full court is seen (including both backgrounds).

Figure 2 shows a camera setting that could be used. It is recommended that: I) The camera has a symmetrical view of the court (to reduce the perspective error); II) the camera records at a minimum sampling frequency of 60 Hz (to capture the impact of the ball on the court); III) the bottom of the court is recorded, with a margin of at least 4 m from the baseline (so as not to lose impacts that go too long).

After performing the 80 strokes, the bounces of the ball can be digitized using specific software. The coordinate origin must be selected in the corner of the backhand part of the court (for a right-handed player), on the side where the targets are located. Within a Windows environment Kinovea software is recommended ([www.kinovea.org](http://www.kinovea.org)). A valid alternative for Mac environment is the Tracker Video Analysis and Modelling Tool (<https://physlets.org/tracker/>). In order to reduce the measurement error, it is recommended prior to performing the test to place a series of balls at known points on the court (see Figure 3) and calculate a regression line, which predicts the real bounce of the ball based on the digitized 2D coordinates (Delgado-García et al., 2019), or apply the 2D DLT calibration algorithm (Vergauwen et al., 1998). Another option is to use specific software, such as SkillSpector or Check2D (Dunn et al., 2012). Once the coordinates of the ball bounces are obtained (expressed in cm), these coordinates are entered in the Excel spreadsheet. This then computes the 95% confidence ellipse, which covers with a 95% of probability the true population mean (Schubert & Kirchner, 2014), for the forehand and the backhand stroke, in addition to a series of parameters related to the way in which the shots are distributed in the space: the length of both axes of the ellipse, the tilt of the ellipse, its eccentricity, the area and the location of the centre of the ellipse on the x-axis and on the y-axis. Supplemental theoretical information about the confidence ellipses and about parameters described can be found in the works of Delgado-García et al.

(2019), Schubert & Kirchner (2014), Shinya et al. (2017) or Yamamoto et al. (2018). To better understand the maths underlying the calculation of confidence ellipses, it is recommended to consult the “Real Statistic Using Excel Package” page (Zaiont, 2016), which is where Excel formulas have been extracted from. The present article will focus primarily on explaining how the Excel sheet is used and how to interpret the results, rather than on the mathematical and/or statistical underpinnings.

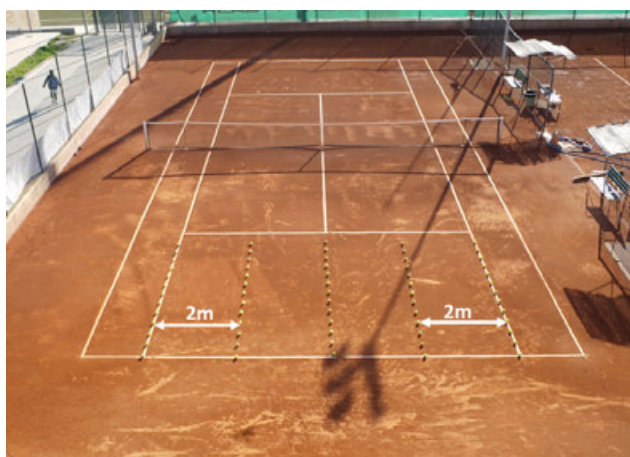


Figure 3. Example of a set of balls located at known positions and used to compute the regression line that allows to predict the real bounce of the ball based on the digitised bounce. The balls in each column have a separation between them of 40 cm.

### How does the Excel book work?

The Excel spreadsheet can be downloaded from [here](https://tennisstrokeevaluation.wordpress.com/) (<https://tennisstrokeevaluation.wordpress.com/>). This link also includes a videotutorial of the use of this Excel sheet and some real examples. Instructions appear in the first Excel spreadsheet ("Instructions"). It explains how the 2D-coordinates of the bounce of the ball are obtained using Kinovea software. In the spreadsheet "Accuracy analysis" only grey shaded cells should be modified. The user must indicate the dominance of the tennis player in cell E5 (with the exact words in uppercase "RIGHT" or "LEFT"), the distance of the centre of the target respect to the sideline (cell E6) and the baseline (cell E7) and the type of test performed (there are four possible tests, explained in Table 1). After that the user must paste the 2D coordinates of the ball

bounces (in centimetres) obtained from Kinovea in range E10:F89. Once the 80 hits of the test have been pasted (it is necessary to fill in the 80 rows so that the mathematical calculations are correct), the following data are automatically produced:

- The length of the 95% confidence ellipse axes (cells V15 and V16 and AB15 and AB16).
- The angle that forms the long axis of the 95% confidence ellipse with the baseline (V17 and V18 and AB17 and AB18) and with the sideline (an angle of 0 degrees indicates that said axis is completely parallel to the sideline) in cells V19 and AB19. Since this information is repetitive, for the interpretation of the results only the angle with respect to the sideline (tilt) will be used. If the ellipse is oriented towards the inside of the court the tilt will be positive (direction changed for the ellipses of the forehand and backhand strokes).
- Eccentricity of the 95% confidence ellipse in cells V20 and AB20. This value ranges from 0 to 1. A value of 0 corresponds to a circle. The closer to one this value is, the more eccentric the ellipse is (more oval shape).
- The 95% confidence ellipse area in cells V21 and AB21. It gives information about global accuracy. A higher area means a less accurate stroke.
- The distance from the centre of the ellipse to the centre of the target on the x-axis and on the y-axis (cells V22 and V23 and AB22 and AB23). It is generated with the means of the coordinates of the bounces of the balls on the x and y axes (cells G94, G96, G107 and G109) and with the distance of the target to the sideline (cell E6) and to the baseline (cell E7). A negative value indicates that the centre of the ellipse is between the centre of the target and the sideline and a positive value indicates that it is closer to the centre of the court. Those values give an idea of the trend of the shots.

Columns G contain the errors: the shot that bounce out of the limits of the singles tennis courts (“out”), the ball that bounce out of the limits of the camera field of view (“out of view”) and the balls that does not pass over the net (“net”). The sum of those three values is the total of errors of the player. The balls that go out from the singles tennis court are

considered for plotting the 95% confidence ellipse. Columns H:I and L:S are used to calculate the different parameters of the ellipse. As mentioned, all these calculations are well explained on the Zaiontz (2016) website. The confidence ellipse is generated with the covariance matrix of the x and y coordinates of the ball bounces of each of the strokes (shown in cell ranges R15:S16 and R31:S32). The covariances matrices allow to compute the two higher

eigenvalues, assuming that the trace of the covariance matrix and the product of the eigenvalues is equal to the determinant of the matrix. These equations (two for each stroke) are solved with parameters in cells P23:S23 and P39:S39 and eigenvalues are shown in cells R25 and R26 (for 1st stroke) and R41 and R42 (for 2nd stroke). The remaining formulas are shown in table 2.

Table 2.

*Excel formulas used to compute confidence ellipse parameters*

Parameter	1 <sup>st</sup> Stroke	2 <sup>nd</sup> Stroke
a-axis	=SQRT(MAX(R25:R26))*SQRT(S27)	=SQRT(MAX(R41:R42))*SQRT(S43)
b-axis	=SQRT(MIN(R25:R26))*SQRT(S27)	=SQRT(MIN(R41:R42))*SQRT(S43)
θ (rad)	=(ATAN2(S15;MIN(R25:R26)-MAX(R15;S16)))*-1	=(ATAN2(S31;MIN(R41:R42)-MAX(R31;S32)))*-1
θ (deg)	=DEGREES(V17)	=DEGREES(AB17)
Tilt (deg)	=90-V18	=AB18-90
Eccentricity	=(1-(V16/V15)^2)^0.5	=(1-(AB16/AB15)^2)^0.5
Area (m <sup>2</sup> )	=(V15*V16*PI())/10000	=(AB15*AB16*PI())/10000
CE-x (cm)	=G94+(100-E6)	=(100-E6)-G107
CE-y (cm)	=G96+(100-E7)	=(G109+100)-E7

a-axis: long axis of the confidence ellipse; b-axis: short axis of the confidence ellipse; CE-x: Confidence ellipse centre distance on the x-axis to centre of the target; CE-y: Confidence ellipse centre distance on the y-axis to centre of the target.

In addition to this data, two graphs are generated:

- Graph 1. Superposition of both confidence ellipses. This graph allows the user to compare visually the 1st stroke and 2nd stroke ellipses. It is also possible to see the centre of the ellipses relative to a common centre of coordinates. The backhand ellipse is rotated horizontally so as it can be compared with the forehand ellipse (the targets for both strokes are symmetrical).

- Graph 2. Shot distribution in the tennis court and confidence ellipses. It shows the disposition of the ellipse of each stroke on the tennis court (at real scale). Cells AC72 AND AC73 show the stroke to which each of the ellipses correspond (taking into account the lateral dominance of the player). In this graph it is also possible to visually check the

distribution of the bounces and the centre of both ellipses relative to the centre of each target. The scatter plot of the landing of the strokes is generated with columns J and K.

In the “Report for the tennis player” spreadsheet of the Excel workbook a report is displayed (the data is extracted from the Excel spreadsheet “Accuracy Analysis”) that can be given to the player. The sheet “Interpreting the report” provides some reference values with which the results of the player performing the test can be compared. These values have been taken from the database of a previous research work (Delgado-García et al., 2019). In the “Court and ellipse coordinate” spreadsheet there are the x and y coordinates of the confidence ellipses and of the tennis court, information needed to create

graphs 1 and 2 of the “Accuracy analysis” spreadsheet.

## Results

Table 3 shows the parameters of the confidence ellipse of both players, for the forehand and backhand groundstrokes performed in the down the line direction. Figure 4 and 5 present this information in a visual way. The length of the major axis of player one for the forehand is greater than that of player two. In the backhand, player two has a longer major axis. The minor axis is longer in both player for the backhand than for the forehand. The angle formed by the ellipse with the sideline (ellipse tilt) is very similar in both cases. However, the backhand confidence ellipse has a greater inclination in player one. As for eccentricity, all ellipses have an oval shape, except the ellipse of the backhand of player

one, which looks more like a circle. The forehand ellipse area of player two is small compared to the other three ellipses analysed. Only the centre of the ellipse on the x-axis of player one’s backhand stroke was positive. The rest of the centres on the x-axis were negative, remaining between the y-axis and the sideline. On the y-axis this value was positive giving an idea of conservative behaviour on the part of both players (they preferred to perform short shots rather than risking to play beyond the baseline). Maybe if the player had been instructed that the out errors did not produce any kind of penalty and that the shots had to be adjusted as closely as possible to the centre of the target, they would have obtained values in this variable closer to zero. Regarding the number of errors, player two made seven more mistakes (11 vs. 18) with the backhand than player one.

Table 3.

*Confidence ellipse parameters for forehand and backhand ellipses of both players analysed*

Parameter	Player no. 1		Player no. 2	
	Forehand	Backhand	Forehand	Backhand
a-axis (cm)	585	446	517	608
b-axis (cm)	280	363	238	291
Tilt (deg)	6.5	11.7	2.8	0.8
Eccentricity	0.88	0.58	0.89	0.88
Area (m <sup>2</sup> )	51.5	50.8	38.8	55.5
CE-x (cm)	-11	45	-40	-34
CE-y (cm)	171	238	191	225
Errors (n)	16	11	16	18
<i>Out shots (n)</i>	8	9	13	16
<i>Out of camera view (n)</i>	8	2	1	1
<i>Net errors (n)</i>	0	0	2	1

a-axis: long axis of the confidence ellipse; b-axis: short axis of the confidence ellipse; CE-x: Confidence ellipse centre distance on the x-axis to centre of coordinates; CE-y: Confidence ellipse centre distance on the y-axis to centre of coordinates. Out shots: Balls that bounce out of the limit of the singles tennis court. Out of camera view errors: balls that pass over the net but bounce outside the field of view of the camera. Net errors: balls that do not pass over the net.

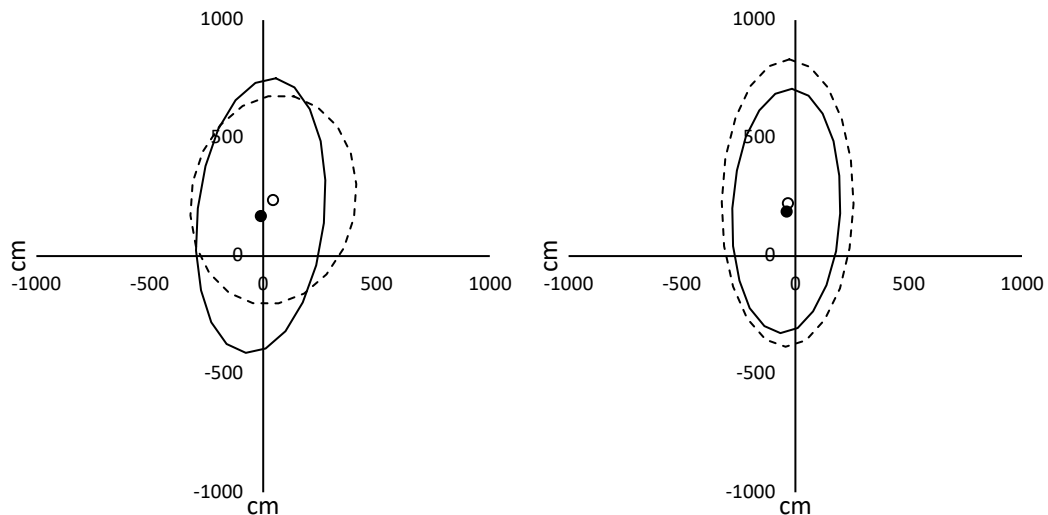


Figure 4. Confidence ellipses of player one (left) and player two (right) for the forehand (solid ellipse) and backhand (dashed ellipse) strokes.

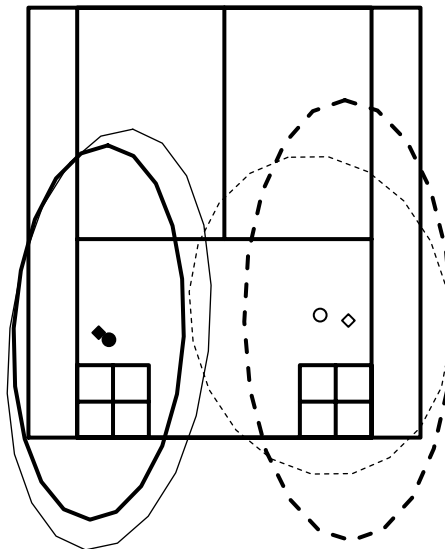


Figure 5. Confidence ellipses displayed relative to the tennis court. Forehand ellipses are in solid lines and backhand ellipses in dashed lines. Confidence ellipses of player two are marked in bold. The centres of the ellipses are indicated by circles (player one) or diamonds (player two).

## Discussion

The test presented does not require expensive materials or a complicated assembly. It is only necessary to place a visible object in the centre of the targets and a camera at the bottom of the court recording the location of the bounces. It can be done

by any coach or scientist and provides interesting information about the distribution of shots in space. It can be used in players of any level by modifying the distance and location of the target, the hitting speed and parameters related to the ball the player receives (frequency of the ball throws of the machine, speed and arrival effect, location of the court to which the

ball bounces both in longitudinal and medio-lateral direction).

In the case of the present study both analysed players showed ellipses of similar characteristics. The area of the ellipse of player one's forehand was very similar to the ellipse area of his backhand. Player two did show a larger area with the backhand, which indicates that this stroke was less accurate. This is consistent with the data in the scientific literature (Delgado-García et al., 2019). Also, the major axes of the ellipses were oriented almost parallel to the sideline as in the mentioned manuscript of Delgado et al. (2019) which has been explained by the Calvin's Launch Window Hypothesis (1983). This theory suggests that the timing of the release of the projectile condition the spatial accuracy. In the particular case of tennis the racket reach high speeds which could difficult the "optimum window of release" (Delgado-García et al., 2019). This oval shape of the ball bounce distribution was more evident for the forehand strokes of both players. Based on this result both players could be advised to focus more on improving longitudinal accuracy rather than medio-lateral accuracy on the forehand. The same goes for the backhand of player two. This could be done performing exercises were the player has to hit at different part of the courts, dividing it in areas in a longitudinal direction or practising strokes modifying some parameters that could affect the flight of the ball such as the hitting speed, heights of the ball over the net (ropes could be used) or the ball spin. A modification of the racket parameters could also be considered, such as the swing-weight or tension of the string since they influence the accuracy (Allen et al., 2016; Bower & Cross, 2005). Player one could be advised to work his backhand both laterally and longitudinally (his ellipse is less eccentric, has a shape more similar to a circle). It is also recommended that both perform exercises in which they are forced to target the baseline (the centre of their ellipses on the y-axis was positive, indicating that they had a tendency to perform short shots).

The present study has some limitations. Excel spreadsheet does not yet provide a database with which the user can compare the results of the players

evaluated depending on the level of play, the age, the sex or the direction of the strokes. We believe that it is necessary to generate a database large enough to be able to evaluate the test results of a particular player, taking into account those characteristics. It would be interesting to translate the numerical results into more understandable adjectives for the coaches and to even classify the player at a game level based on the test results. Another possible limitation of this tool is that it is not automatic like other systems mentioned in the introduction. Although it requires a digitalization process, it presents certain strengths: it can be used with any conventional camera in complicated lighting conditions such as indoor tennis courts with low light or outdoor courts with contrast of light and shadow. Definitely we think that this research shows an interesting tool to investigate accuracy in detail in the case of tennis. Currently, the number of studies on accuracy and its relation with performance in tennis is rather scarce. Accuracy has been studied more in depth for other throwing sports such as baseball, cricket or handball (Freeston, Ferdinands, & Rooney, 2015, 2007; Freeston & Rooney, 2014; van den Tillaar & Ettema, 2006). The test proposed in this work and the Excel tool that accompanies it is expected to be valuable for scientists who want to study accuracy. In our opinion, there are still a large number of factors that can affect accuracy during play and their impact should be studied in greater depth than what has been done so far, such as: fatigue (Lyons et al., 2013), racket characteristics (Bower & Cross, 2005), mental aspects (Robin et al., 2007), variables related to the ball that approaches the player (Bower & Sinclair, 2007) or with the ball that leaves the racket (Knudson & Blackwell, 2005). Since the test does not require complex technical knowledge or setting-up, it is also expected that coaches with limited access to high end technologies can use it. In fact, the test could be applied at different times of the season to see progression of players in relation to their accuracy. This could be of special interest in high level players and professionals where changes may be less noticeable than in lower level players and where an area-based target system may not be sensitive

enough to detect improvements in accuracy. In many cases, in addition to measuring the accuracy, it will be of interest to evaluate the speed of the stroke, since both variables are closely related to each other (Holzer, Reischl, & Fetz, 1994 and Landlinger et al., 2012). The latter can be done with the use of a speed radar that measures the speed of the ball or with an inertial sensor that measures the speed of the racket.

## Conclusions

The field test shown and the accompanying Excel spreadsheet provide valuable information for coaches and scientists and assist them in assessing the hitting accuracy with low cost and high precision. This paper shows an example of its implementation with two advanced level players. It was demonstrated how the outcomes of an affordable field test can easily be turned into tangible parameters that can inform training targets related to stroke accuracy, something which to our knowledge was previously not easy to perform.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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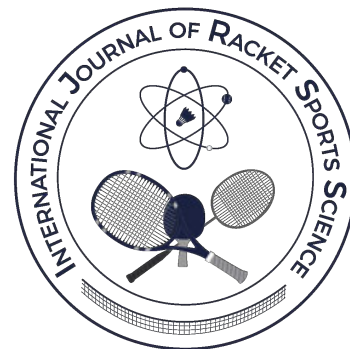
# Comparison of hip joint mechanical energetics in table tennis forehand and backhand drives: a preliminary study

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## Abstract

Hip joints are highly involved in table tennis. Some authors found both pelvic angular velocity and hip joint torques are related to the racket velocity. Others have also demonstrated how some of the best players have higher ranges of motion of the lower-limb joints. Therefore, the mechanical work generated by the playing-side-hip can be seen as indicator of the playing intensity associated with different strokes. The aim of this study was to quantify the hip joint mechanical work and power during four classical strokes. Motion capture acquisitions were performed on two international players. A biplanar radiographic acquisition was also performed to personalize the biomechanical model. Hip joint velocity and torques were calculated on the dominant side, allowing mechanical power and work to be calculated between the end of backswing and the ball impact. The highest level of mechanical work from the hip joint was found for forehand drive against backspin and forehand topspin drive with pivot. A backhand drive required the lowest hip mechanical work, and the forehand drive against topspin was found to be intermediate. The lower work required from the backhand stroke makes it suitable as a waiting stroke.

Keywords: *Table Tennis, Hip Joint, Mechanical Work*

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## Introduction

One of the most used stroke in table tennis is the topspin forehand, which accounts for 36% of the total shots performed during a game (Lanzoni, Di Michele, & Merni, 2014). Previous kinematic studies on table tennis focused on evaluating the relationship between joint angles and racket velocity during topspin forehand drives (Bańkosz & Winiarski, 2018; Iino & Kojima, 2009; Qian, Zhang, Baker, & Gu, 2016). Few of them focused on lower limb kinematics (Qian et al., 2016) but it was observed that the best players tend to exhibit a higher hip range of motion during topspin forehand drives than players of a lower level. Kinetic aspects of table tennis have been less studied: only one study focused on hip kinetics (Iino, 2017) in which a positive correlation was found between the horizontal velocity of the racket and both hip joint torques and pelvis angular velocities.

Energetic aspects (i.e. mechanical work and power), which are at the interface between kinematics and kinetics analysis, have been studied in other sports, such as rugby tackles (Hendricks, Karpul, & Lambert, 2014), tennis serves (Martin et al., 2014) or badminton shots (Rasmussen, Kwan, Andersen, & de Zee, 2010), allowing the understanding of the physical demand of specific sport associated gestures.

In table tennis, the energy flow from the trunk to the racket arm has already been investigated and this study showed that most of the energy transmitted to the racket came from the trunk, and that lower limbs and trunk muscles are supposed to generate most of the energy transferred to the racket during topspin forehand drive (Iino & Kojima, 2011). Consequently, studying energetic aspects in table tennis can provide insights into athletes' striking performances (van der Kruk, van der Helm, Veeger, & Schwab, 2018).

Regarding the involvement of pelvic angular velocity and hip joint torques in table tennis striking performance (Iino, 2017; Qian et al., 2016), the hip joint mechanical power and work can be seen as indicators of the playing intensity required by the different table tennis strokes. Hence, the aim of this study was to quantify the hip joint mechanical power and mechanical work during four classical table tennis

strokes: topspin forehand drive on topspin incoming ball, topspin forehand drive on backspin incoming ball, topspin forehand drive with pivot, and backhand drive on topspin incoming ball. It has been hypothesized that hip mechanical work and power would be higher during forehand drive on backspin incoming ball since the player has to produce more spin.

## Material and methods

### *Participants*

Two right-handed males; both international table tennis players from France, were involved in this study, in line with the previously obtained ethical agreements (2018-A00173-52). Subjects were informed of the protocol and signed a written informed consent form before the beginning of the experiments. Subjects' characteristics were: age: 20 and 22 years; body mass: 86 and 75 kg; and height: 1.92 and 1.87 m, for participant 1 and 2, respectively.

### *Data collection*

Participants were equipped with 88 reflective markers fixed on their whole body plus three on the racket (Figure 1). This allows a full-body analysis and the definition of segment coordinate systems, in line with recommendations from the International Society of Biomechanics (Wu & Cavanagh, 1995; Wu et al., 2002, 2005). After completing their own warm up routine to get comfortable with the environment and experimental setup, the participants completed at least 5 cycles of each of the four activities: topspin forehand drive on topspin incoming ball (FH\_TS), topspin forehand drive on backspin incoming ball (FH\_BS), topspin forehand drive with pivot on a topspin incoming ball (i.e. a topspin forehand drive with a lateral displacement of the player) (FH\_D), and a backhand drive on a topspin incoming ball (BH\_TS). Participants played against each other during the acquisitions for all activities but only one player was monitored at a time. For FH\_BS, the studied player received only one ball, five times in a row. Locations of the reflective markers were captured using a 15-camera optoelectronic motion capture system (Vicon® System, ©Oxford Metrics Inc., UK, 200 Hz)

with simultaneous recording of ground reaction forces obtained with two force plates (AMTI BP6001200, USA, 1000 Hz). Right after the motion capture and without removing the markers, participants underwent a low dose biplanar radiographic acquisition (EOS, EOS Imaging) in a neutral standing posture. The biplanar radiographs were then used to perform 3D reconstructions of the spine, pelvis, femurs, tibias, fibulas and the markers, which were used to personalize the biomechanical model.



Figure 1. Photo of the research station

### Data processing

Kinematics were obtained through a multibody kinematic optimization procedure (Lu & O'Connor, 1999) with a personalized full-body model (Bourgain et al., 2018) based on previously available models (Raabe & Chaudhari, 2016; Seth, Matias, Veloso, & Delp, 2016). The data processing was performed in OpenSim 3.3 (Delp et al., 2007). First, the multibody kinematic optimization provided joint angles. Then, joint angles were smoothed with a Butterworth filter (5Hz, zero-phase, with a total order of 4). Finally, force-plate data was used for computing net joint torques with the inverse dynamics tool implemented in OpenSim 3.3.

### Power and mechanical work computation

Hip joint angular velocity and torque on the playing side (i.e. right side for both participants) were projected into the same orthogonal coordinate system and then multiplied to obtain the hip joint mechanical power. This mechanical power was calculated during

each cycle of all four activities and normalized with respect to the body mass of the participant. The mechanical work has been calculated as the integral sum of the normalized hip power with respect to time during the strike phase. This phase was defined between the end of the backswing (i.e. the instant when the racket was at its lowest position) and the impact between the ball and the racket (here defined as the instant of maximal racket linear speed). Hip joint mechanical power and mechanical work was only calculated on the playing side (arm with the racket) because only one foot was on the force plates simultaneously. Because mechanical power can be positive or negative, we therefore distinguished the negative work, which is the time integral of the power when the power is negative (Figure 2); the positive work, which is the time integral of the mechanical power when the power is positive, and the total mechanical work, which is the sum of positive and negative works. The maximal racket speed during every stroke was also determined for the two participants.

### Statistical analysis

Considering the low number of trials per activity, a non-parametric Wilcoxon-Mann-Whitney test was performed to determine if there was any significant difference ( $\alpha = 0.05$ ) across the activities for each variable of interest.

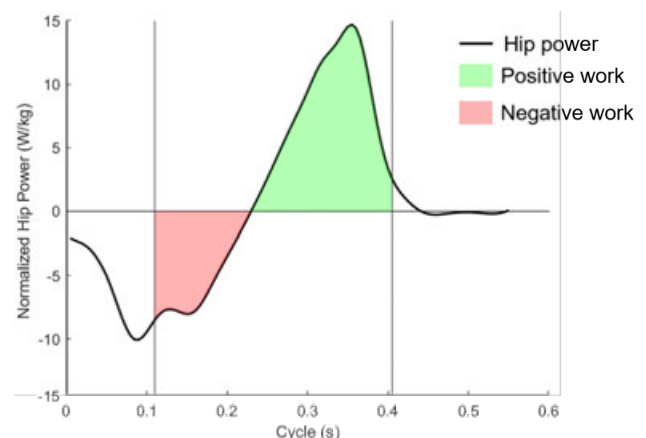


Figure 2. Example of the time course of the hip joint mechanical power (normalized with participant's mass) for one trial of one participant. The two vertical lines delimitate the strike phase. Shaded areas represent positive (green) and negative (red) works.

## Results

The maximal racket speed has been found higher in all four activities for participant 1 than for participant 2 (Table 1). For both participants, the maximal racket speed was the highest during the FH\_BS. The participant 1 had significantly higher racket speed than participant 2 during all activities (Table 1).

For both participants, maximal hip joint mechanical power on the playing side was the lowest for BH\_TS (Figure 3). For participant 1, the maximal power was obtained during FH\_BS and FH\_D followed by FH\_TS. For the second participant, maximal powers were found on both FH\_TS and FH\_D, whereas BH\_TS was the activity with lowest maximal power, preceded by FH\_BS.

Table1.

Maximal racket speed during the strike (mean  $\pm$  SD) for all activities and for both participants. The \* means that there were significant differences between the players.

	FH_TS (m/s)	FH_BS (m/s)	FH_D (m/s)	BH_TS (m/s)
Participant 1	14.5 $\pm$ 1.2	19.0 $\pm$ 0.3	16.7 $\pm$ 1.7	13.3 $\pm$ 1.4
Participant 2	13.2 $\pm$ 0.4	17.6 $\pm$ 0.4	16.0 $\pm$ 0.5	11.7 $\pm$ 0.2
p-value	0.007*	0.007*	0.007*	0.015*

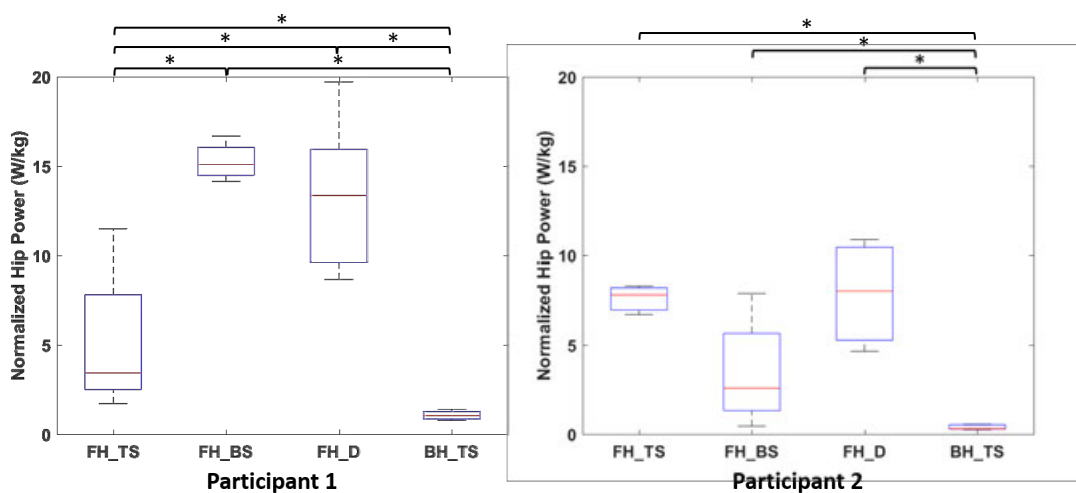


Figure 3. Boxplot of the maximal normalized hip joint mechanical power for the four activities (5 trials by boxplot) of each participant. The \* means that there were significant differences between the activities.

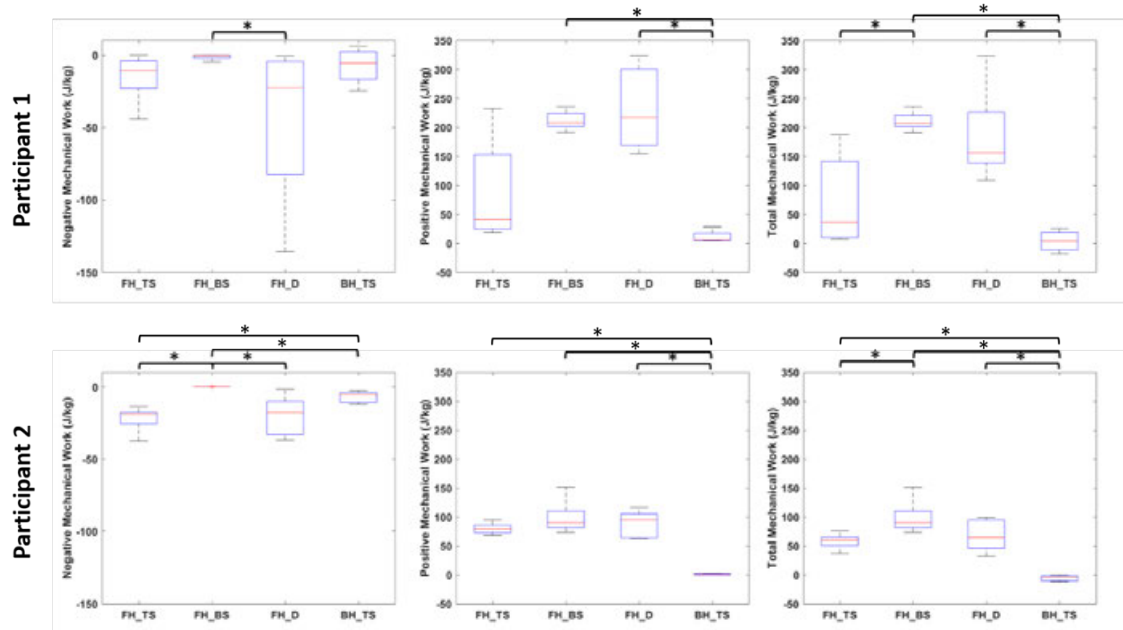


Figure 4. Boxplot of the negative, positive and total mechanical works during the strike phase for both participants during the four activities (5 trials by boxplot). \* indicates a significant difference between the activities.

## Discussion

Values of racket speed at impact were consistent with the literature for FH\_BS, which was of 18 m/s on average (Huang et al., 2013) against balls with backspin. It is also consistent for BH\_TS, which ranged between 12 and 16 m/s (Iino & Kojima, 2016). Furthermore, participants from this study (Iino & Kojima, 2016) performed backhand strikes against a ball-projecting machine whilst in the present study, participants faced each other, which led to match-like situations with comparable spin and ball speed.

Since the statistical analysis has been made on only five cycles for each activity, the significant differences may not be interpreted as strong differences but should be considered as tendencies regarding the differences between participants or activities.

Results have shown that both hip joint mechanical power and mechanical work were lower during the backhand drives than during the other studied strokes. Moreover, there was very little mechanical work produced during this stroke. Indeed, the low total mechanical work is not due to compensation

between positive and negative power but rather due to low absorption and production of mechanical energy. This activity is the one that requires the lowest hip physical demand during games. Consequently, players can use backhand drives as a waiting strategy because it necessitates low energy at the playing hip to perform this gesture.

The FH\_BS activity required the maximal hip mechanical power for the first participant but not for the second. This means that the hypothesis cannot be validated as a generality. Nevertheless, hip joint mechanical power was higher for participant 1 than for participant 2 (Figure 3) and can be related to the higher racket speed observed for the first participant than for the second (Table 1). This result agrees with findings from previous studies investigating pelvis angular velocities and hip joint torques. However, the difference in racket speed is not high (1.42 m/s during FH\_BS which correspond to an increase of 8% of the racket speed) whilst the difference of maximal hip power is of approximately 15 W/kg (which corresponds to an increase of 150%). These differences in hip joint mechanical power directly impact the mechanical work generated at the hip. Despite both participants having similar negative mechanical work during the strike, the first

participant managed to generate more positive mechanical work which led to a higher total mechanical work. Hence participant 1 can be seen as more effective than participant 2.

The FH\_D activity, which is a forehand with a lateral displacement, required higher mechanical work and power than the FH\_TS activity for the first participant. This higher hip joint mechanical work and power directly impact the racket maximal velocity, which is higher for the FH\_D activity than for the FH\_TS one. However, even if the second participant has a higher maximal racket velocity during FH\_D activity than during FH\_TS activity, there was no difference in the hip mechanical power and work during these two activities. This means that the hypothesis stating that the mechanical work and power would be higher during FH\_BS than FH\_TS cannot be validated.

## Conclusion

Based on previous knowledge about the relation between the racket velocity and both the pelvic angular velocity and the hip joint torques, this study aimed to investigate the hip mechanical energy during four classical table tennis strokes. This preliminary study showed that backhand drives can be used as a waiting strategy while conserving energy in the case of the playing side hip. On the contrary, forehand strokes against balls with backspin require high hip joint mechanical work and power to be produced. Hence, backspin strokes can be used to increase hip opponent exhaustion. Nonetheless; this can increase the exposure to opponent attack.

Through the distinction of positive and negative mechanical works, it was possible to analyze the biomechanical efficiency of the stroke between participants. This distinction allowed observing that both participants used different strategies to generate hip power. However, at this stage, this analyze was limited to the playing-side hip.

Finally, this study is a preliminary study and more subjects are needed to confirm the results. It would also be interesting to study the power flow, including that of the lower limb, during these classical table tennis strokes.

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## Footwork technique used in elite table tennis matches

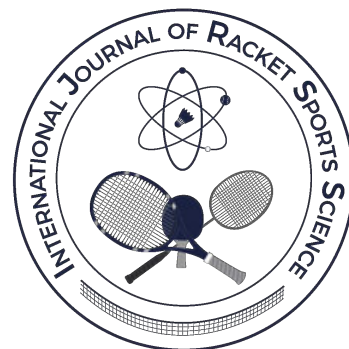
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### Abstract

Notational and Match analysis are very well-recognized methods to collect information about the most common technical-tactical performance indicators in table tennis: footwork and stroke types. The aim of this study was to compare footwork distributions in men (M) and women (W) elite table tennis competitions. Nine men's and nine women's matches were analyzed. All players were in the top 120 (M) and 111 (W) positions of the ITTF world ranking. An expert coach analyzed game video recordings in slow motion with the software Kinovea and collected data about the footwork types used by the players during the games. The results showed differences between M and W: M prefer to use one step (35.6%, W: 21.9%), W prefer to hit the ball without performing any step (W: 40.2%, M: 20.4%), the chassé is equally used (M: 19.7%, W: 21.7%), and the crossover is mainly used by M (11.1%, W: 3.7%). The pivot is mainly used by M (9.9%, W: 7.8%), and W prefer the slide (4.9%, M: 3.2%). In conclusion, this study can be useful for physical trainers, performance analysts, and coaches, to design specific footwork training sessions for M and W elite table tennis players.

Keywords: *Racket sports, Match Analysis, Notational Analysis, Footwork*

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## Introduction

Table tennis is one of the most popular and played racket sports in the world and has been included in the Olympic programme since 1988. Technical and tactical skills are very well recognised as the most important performance factors in table tennis. They could be evaluated using notational analysis in order to collect and summarise sport-specific performance indicators (Hughes, 1998; Hughes & Barlett, 2002). Stroke types were examined comparing different table tennis groups or individual players (Djokic, 2002; Drianovsky & Otcheva, 2002; Zhang et al., 2014; Malagoli Lanzoni et al., 2014).

Another crucial aspect of the specific technique is the footwork performed before hitting the ball, as using a proper footwork technique allows the athletes to be in the best position for an effective shot (Malagoli Lanzoni et al., 2007).

Fuchs et al. (2018) reviewed all the literature about match analysis in table tennis, including a dedicated paragraph about footwork analysis and its development. In 2003, Tepper presented a basic classification of the main steps used by table tennis players. In 2007, Malagoli Lanzoni et al. suggested a standard definition of the different types of steps used by the athletes: one step, short steps (chassé, slide, turn/pivot), crossover, and “stroke without step”. Malagoli Lanzoni et al. (2007) collected data about four top-class table tennis players, showing that the most frequent steps are: one step (37.3%), turn/pivot (21.1%), chassé (15.2%), stroke without step (11.5%), slide (7.5%), and crossover (7.3%). In 2009, Malagoli Lanzoni and Lobietti compared footwork techniques used by two groups of international and national players. Footwork analysis continued to evaluate different kinds of steps in relationship with other variables: shots and outcome of the rallies (Malagoli Lanzoni et al., 2010), and different group of players (Malagoli Lanzoni et al., 2013a, b, 2014).

To improve footwork technique, coaches use a large variety of exercises focused on a similar distribution of steps, for men and women, respectively, not clearly distinguishing training sessions.

The purpose of this study was to compare footwork distributions in men (M) and women (W) elite table tennis competitions.

## Methods

Nine M and nine W matches were randomly selected, and one match per player was taken into account. The 18 male players were in the first 120 positions of the ITTF official World Ranking, whereas the 18 female players were in the first 111 positions when the matches were played.

All players adopted an offensive playing style because they did not use long-pimple rubbers, the typical rubbers used by defenders, and they were not using a backhand chop stroke when playing far from the table.

All the players were right-handed, considering the hand used to hold the racquet.

The mean  $\pm$  SD age, height, and body mass were  $29.8 \pm 4.7$  years,  $179.5 \pm 6.9$  cm,  $73.5 \pm 5.8$  kg for males, and  $24.3 \pm 3.7$  years,  $162.9 \pm 6.3$  cm,  $55.0 \pm 5.0$  kg for females.

The selected matches were played in the Olympic Games, Team World Championships, ITTF Pro Tour Circuit, ITTF World Cup, and Pro Tour Grand Finals.

The matches were downloaded from the official websites [www.ittf.com](http://www.ittf.com) and [www.ettu.org](http://www.ettu.org). Each match was analyzed in slow motion (0.2 recorded speed) with the software Kinovea ([www.kinovea.org](http://www.kinovea.org)).

Data collection was carried out through a Visual Basic-based application to create a data base directly in the Microsoft Excel software. An experienced table tennis coach collected the data about the footwork technique used during the matches. Krippendorff's alpha (Krippendorff, 2004) was calculated to evaluate intra-observer reliability. Alpha value can range between -1 and 1, and 1 indicates perfect agreement. For footwork type, alpha value was 0.99. Previous studies showed a very good intra- and inter-observer reliability of footwork types using the present classification and methods (Malagoli Lanzoni et al., 2012; 2014).

The statistical analysis was performed with the SPSS statistical software, performing one way ANOVA with significance indicated as  $p \leq 0.05^*$ ,  $p \leq 0.01^{**}$ .

The classification of footworks included the following categories (Malagoli Lanzoni et al., 2007): one step (Fig. 1), chassé step (Fig. 2), slide step (Fig. 3), crossover (Fig. 4), pivot step (Fig. 5), and shot without step (Fig. 6).

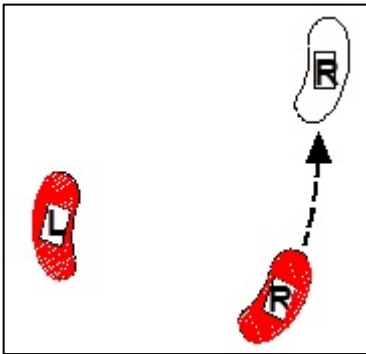


Figure 1. One step

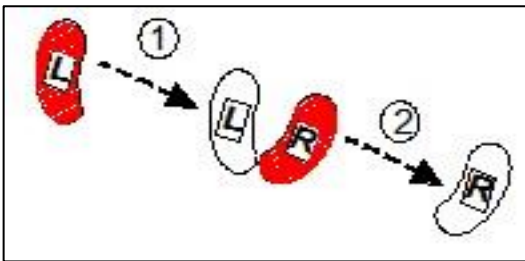


Figure 2. Chassé step

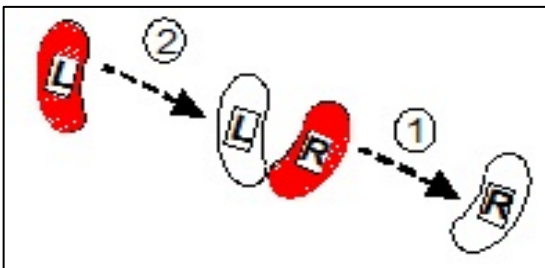


Figure 3. Slide step

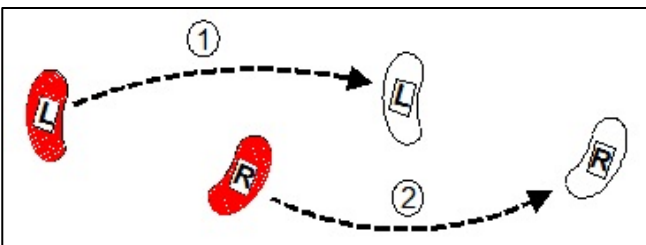


Figure 4. Crossover step

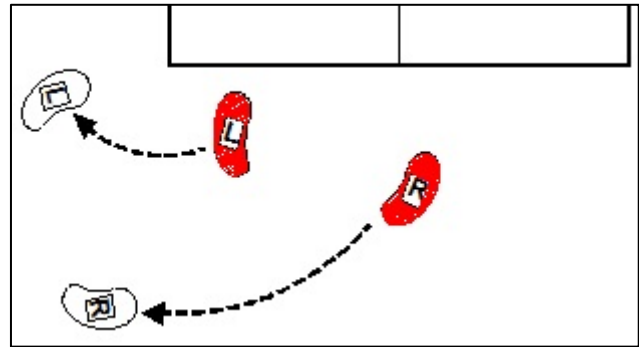


Figure 5. Pivot step

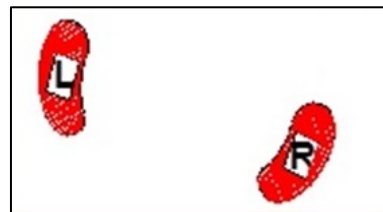


Figure 6. Shot without step

## Results

A total of 18 matches (M = 9, W = 9), 96 sets (M = 50, W = 46), 1713 rallies (M = 902, W = 811), and 7095 steps (M = 3322, W = 3773) were considered. One way ANOVA showed significant differences ( $p \leq 0.05^*$ ,  $p \leq 0.01^{**}$ ) between M and W in the distribution of footwork types.

Table 1 shows the footwork distribution in M and W. M prefer to use one step (35.6%, W: 21.9%), W prefer to hit the ball without performing any step (W: 40.2%, M: 20.4%), the chassé is equally used (M: 19.7%, W: 21.7%), and the crossover is mainly used by M (11.1%, W: 3.7%). The pivot is mainly used by M (9.9%, W: 7.8%), and W prefer the slide (4.9%, M: 3.2%).

Table 1.

*Distribution of footwork types for men (M) and women (W) athletes ( $p \leq 0.05^*$ ,  $p \leq 0.01^{**}$ )*

.FOOTWORK	M	W
one step**	35.6%	21.9%
shot without step**	20.4%	40.2%
chassé step	19.7%	21.7%
crossover step**	11.1%	3.7%
pivot step	9.9%	7.8%
slide step*	3.2%	4.9%
Total	100.0%	100.0%

## Discussion

The aim of this study was to compare footwork distributions in men (M) and women (W) elite table tennis competitions.

The results showed similarities between M and W in using chassé step which is a basic technique used to perform various sets of shots by making easy side movements in front of the table (Malagoli Lanzoni et al., 2014).

The pivot step is exclusively performed to play forehand shots from the backhand corner (Malagoli Lanzoni et al., 2014), and it is used by M and W with a similar distribution (9.9 and 7.8%). Moreover, M and W players showed limited differences in using the slide step, consisting of sliding laterally first the foot corresponding to the direction of displacement, and then the other foot (Malagoli Lanzoni et al., 2014). W prefer to use this technique, compared to M, showing limited differences ( $p \leq 0.05$ ).

Instead, the main differences between M and W table tennis elite athletes with respect to footwork types concerned the One step, Shot without step, and crossover step ( $p \leq 0.01$ ).

The one step is mainly used to answer the serve, and represents a key step for the first phases of the rally (Malagoli Lanzoni et al., 2014). It is mainly used by M to hit a close-to-the-net ball at the beginning of every rally. The difference to W could be connected with the use of long services performed in W competitions.

The shot without step category was strongly associated with W category. This demonstrates a less

dynamic play concerning the footwork technique, connected with the use of backhand shots, which confirms previous literature about W footwork specific technique (Malagoli Lanzoni et al., 2013a).

The crossover allows the player to move for relatively long distances in the shortest time possible, and it is representative of the modern dynamic play (Malagoli Lanzoni et al., 2014). It is mainly used by M athletes and it is most likely linked to an offensive and risky style of play.

Hypothetical explanation of the different percentages of types of footwork can also be addressed considering constitutional differences, played systems, ball speed, placement of the balls, etc. It may be concluded, therefore, that the difference between M and W in elite table tennis competitions may have multifactorial origins, showing links with both technical and physical aspects.

This study should be extremely useful for physical trainers, performance analysts, and coaches, to design specific training sessions for M and W elite table tennis players, in order to improve footwork technique. Moreover, it should be used to plan specific physical trainings in order to prevent injuries in both categories planning different exercises.

In conclusion, future perspectives should be linked to the comparison of different categories of players, evaluating the connection with other variables (directions, shots, outcome, etc), and including quantitative analysis about footwork technique.

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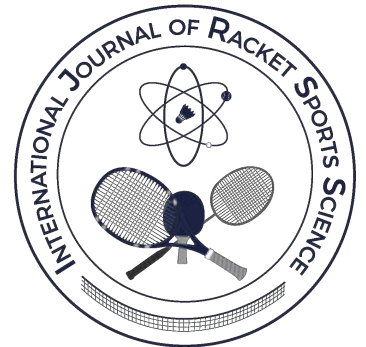
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# Psychobiosocial states in competitive badminton: Similarities and differences between juniors, adolescents and adults

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## Abstract

Emotions affect the way elite athletes respond during competitive play. Elite athletes who identify and regulate emotions can increase their consistency and optimize high quality play. This cross-sectional study examined the extent to which psychobiosocial states of elite badminton players vary by age. Ninety-one elite badminton players in three age groups (lower juniors, upper juniors, and adults) rated their post-play perceptions on eight components of psychobiosocial states (Bortoli, et al., 2008) for both their best and worst performance during the tournament. Descriptive statistics assessed the relative strength of emotions on each item and an analysis of variance examined differences between the three groups. Age differences were found in the perception of the psychobiosocial states in competitive badminton matches in terms of most identified states and intensity. The findings inform coaches' understanding athlete's individual zone of optimal function (IZOF) and can help them cope with psychobiosocial states during matches.

**Keywords:** *Psychobiosocial States, Developmental, Age Differences, Juniors, Badminton*

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## Literature review

Emotion plays a significant role in athletic competitions, particularly for elite athletes (Deci, 1980). Performance in competitive settings is not only a product of long training sessions, natural proclivities but also influenced by split-second responses of mental status. For the past three decades, sports psychologists have explored relationships between anxiety and performance, emotions and performance. More recently, the relationship between multiple components has emerged under a single concept; psychobiosocial states: Emotion, motivation, bodily reaction, operation, communication, volition, motor behaviour and cognition (Bortoli, Bertollo & Robazza 2009). At the same time, there are developmental differences in all of these psychobiosocial states. Split-second mental reactions influenced by the psychobiosocial states. However, the effect and interaction within and among the states depend on the development of the athlete, typically in age ranges. For example, junior athletes are more likely to perceive and react differently from their adult counterparts.

### *Psychobiosocial states*

In 2000, Hanin defined the Individual Zone of Optimal Function (IZOF) as "a focus on describing, predicting, explaining, and regulating performance-related psychobiosocial states affecting individual and team activity" (p.66). The eight psychobiosocial states can be both positive or negative and can have the optimal or dysfunctional influence on performance. The key factor is the relative intensity that the athlete experiences in Psychobiosocial states that creates a personalized IZOF. Understanding players IZOF can modulate performance, predict future performance, and support coaches as they train players to identify and regulate components in future performance. If coaches and players can better regulate mental status, it is hypothesized that they can improve their performance. Failure to regulate mental status can result in persistent under-performance in highly competitive matches. Based on the underpinnings of IZOF profiles (Hanin, 2000; Hanin & Ekkikakis, 2014), researchers developed a standardized tool to assess

athletes' states during competitions. Eight psychobiosocial states are contributing to athletes' performances in various sports contexts: cognitive, emotional, motivational, operational, bodily, volitional, motor behavioural, and communicative (Bortoli, Bertollo, & Robazza, 2009; Bortoli, Bertollo, Comani, & Robazza, 2011; Robazza, Bertollo, Ruiz, & Bortoli, 2016).

### *Developmental differences in 8 psychobiosocial states*

The impact of psychobiosocial-performance happens in real time and can change in a matter of seconds during competition. For athletes to effectively regulate their multiple states, they have to quickly identify the states they are trying to regulate. This ability differs by age and by psychobiosocial component. A brief description of the 8 states demonstrates that each are important and influential in the heat of close competitive play, reaction of a perceived bad call by an official, or poor execution on a routine action.

### **Cognition**

Children and adolescent's attention spans and strategies used to reason and make sense of the world differ from adults. They move from very concrete thinking toward abstract thinking, and eventually, most adults proceed toward more dialectic thinking strategies. These differences are partially explained by the unique ways in which the different developmental groups process various stimuli presenting to them. With more advanced stages of cognitive development, older adolescents exhibit more efficient strategies compared to their younger counterparts in multiple sports competition settings (Micklewright et al., 2012; French & McPherson, 1999).

### **Emotion**

Emotional changes experienced in childhood generally differs from emotions in adolescence and adulthood. As children get older and have more experiences to deal with, they can make a more effective prediction of how they will react when the environment provides a stimulus (Barrett, 2017). A longitudinal study of football (soccer) players found that the emotional, interactive process of "reaction and

regulation” differed between adolescents and either children or adults (Piero, Saxbe, & Margolin 2016). Older adolescent athletes showed more effective coping stressors skills than younger players (Reeves, Nicholls and Mckenna, 2009). Neuroscientists suggest that brain structures play an essential role in human emotions. Brain regions, the amygdala, and the prefrontal cortex contribute to human emotion perception and regulation. an intense, fast pace rally (stimuli) might be emotionally perceived stronger to the adolescent than to the children and to the adults (Zald, 2003).

### **Motivation**

Several motivation theories have been examined in a variety of sports contexts including Harter's competence motivation theory to Coaching style. Each demonstrates influence on athletes' perception of their ability and subsequently their motivation to perform. Coaching with mastery goals in mind predicts greater ability perception, motivation, and fun (Weiss, Amorose, & Wilko, 2009). Social status was shown as a more important motivation factor for adolescents than children and adults. Also, there are health/fitness differences between age groups (Brodkin & Weiss, 1990), with younger athletes valuing coaches/parents' opinions more than adolescents and adults.

### **Motor behaviour**

Speed, agility, explosive strength, shoulder strength, and muscular endurance are the most critical five motor components in badminton performance (Tiwarl, Rai, & Srinet, 2011). Players in different age group exhibit different motor abilities due to physical development. Therefore some levels of performance are correlated to physical development status (Filipic, Pisk, & Filipic, 2010). Physical training and repetitive actions can influence footwork and reaction times, but structural motor behaviour is limited by natural aging.

### **Volition**

Zimmerman's cyclical phases model of self-regulation learning examine the relationship between performance, motivation and strategy selection (Zimmerman, 2000). The model and its interactions have been shown to exist in both classroom and sports

contexts (Cleary & Zimmerman, 2001; Zimmerman, 1998). Experienced athletes exhibit higher levels of self-regulation. They organize skills more efficiently, exhibit better recall, and are more accurate in anticipating stimuli (Starkes et al. 1994; McPherson, 1993). A longitudinal study showed that that gaining experience in sports contexts presented better self-regulation in emotion controls in other aspects of life (Oaten and Cheng, 2006).

### **Bodily**

Physical differences play a significant role in sports performances. Height, body mass, aerobic power, muscular strength, endurance, and speed provide performance advantages in most sports (Malina, Bouchard, & Bar-Or 2004), including badminton. A year of maturation, especially during puberty, can be associated with performance differences (Cobley, Baker, Wattie, & McKenna, 2009). Between the ages of 12 to adulthood, male players can grow as much as 90 cm and gain 7-30 kg. Body mass and body fat level dramatically changed from pre-teen to adulthood years (Chahar, 2014; Stang & Story, 2005).

### **Operations**

Badminton involves a high volume of cognitive exchanges, rapid problem solving, and instant crisis identification. Atkinson and Shiffrin (1968) created a model to link information processes to memory, which was known as 'The multi-store model and memory'. This model describes memory in terms of the information flows through a system. Age was a strong predictor in memory recall during the performance. Research shows that CMP increases with increased age. (Hicheur et al., 2017; Tournon & Hertzog, 2004).

This study examined the intensity of 8 psychobiosocial states in elite badminton players and tested the extent to which the states differed by age range. Based on the literature, it was hypothesized that there would be age differences in the 8 states.

### *Research questions*

1. Which psychobiosocial states are most intense during player's recall of their best and worst badminton performance?
2. Are there significant differences in badminton players' psychobiosocial states by age range?

## Method

### Participants

The sample for the study included ninety-one high performing male athletes who participated in the USA Badminton (USAB) sanctioned tournaments during the 2017 season. The sample consisted of thirty juniors between the ages of 10 to 12 (Mean=11.36, SD= .66); thirty late adolescents between the ages of 16 to 19 (Mean =16.9, SD=.84); thirty-one adults between the ages of 23 to 45 (Mean= 32.5, SD=7.93). Table 1 presents the ages, years of competition, and the self-reported days/week training per year.

Table 1.  
*Age, years of competition, and average practice per week*

	Junior (n=30)		Adolescent (n=30)		Adults (n=31)	
	Mean	SD	Mean	SD	Mean	SD
Age	11.36	0.66	16.9	0.84	32.50	7.93
Years of Competition	3.4	1.40	6.48	2.14	14.96	5.95
Training Per Week (Times)	4.24	2.4	3.65	1.49	3.72	1.80

### Measures

The PBS-ST Scale is an assessment of measuring athlete's psychobiosocial state (Robazza, Bertollo, Ruiz, & Bortoli, 2016). The PBS-ST Scale (Bortoli & Robazza, 2008, 2011) contains functional and dysfunctional descriptors of competitive play and has been used in prior studies with several types of sports. Each psychobiosocial State (PBS-ST) includes two or three descriptors. Items include: Emotional (affective functional, emotional-affective dysfunctional, anxiety functional, anxiety dysfunctional, anger functional, anger dysfunctional), Cognitive (functional, dysfunctional), Motor behaviour (functional, dysfunctional), Motivational (functional, dysfunctional), Volitional (functional, dysfunctional), Operational (functional, dysfunctional), Bodily (functional, dysfunctional), and Communication (functional, dysfunctional). The items were randomly ordered. The participants were asked to respond to each PBS-ST on a 5-point Likert scale, ranging from zero (not at all) to four (very much). Intensity ratings were selected on the

following criteria: 0 = nothing at all, 1 = very little, 2 = moderate, 3 = much, 4 = very much. This resulted in each athlete identifying specific functional and dysfunctional content (descriptors) related to each of the 8 performance states and ratings of their intensity. A total PBS-ST score was created by summing across all. Two studies conducted by Robazza et al. (2016) reported evidence for internal validity and construct validity of the instrument.

### Procedure

There were two phases in the implementation of measures for this study. First, Loyola University Maryland Institutional Review Board (IRB) reviewed the proposal and assessed the rights and protections of the participants, especially there are minors involved in this study. Second, the instrument was administered to the participants in various tournaments in the U.S. during the 2017-2018 season. Next, the survey was administrated to athletes between October 2017 to July 2018. The primary investigator (PI) collected the player lists before major USAB sanctioned tournaments. The PI provided a brief introduction to qualified participants

at the beginning of the tournament. The introduction included a description of the purpose of the study and the rights of participants. Athletes who agreed to complete the study indicated their consent to participate. Both parents and players under the age of 18 signed consent and assent forms respectively. Each participant responded to both their best performance in a single match and worst performance in a single match at the end of the respective tournament. There was no time limit to complete the survey and the time to complete varied between 10- 25 min. Participants received two racket grips as a reward for participation in the study.

### Data analysis

Mean scores on each item were calculated for the three age groups. One-way ANOVAs were performed to examine any statistically significant mean differences in PBS-STs for each age group and to determine the relative impact of particular states on best and worst performance across age groups.

## Results

The result of the analysis show that players at all levels rated functional states more highly than dysfunction states during their best performance. Conversely dysfunctional states were rated highly for

the worst performance. This is an intuitive finding that while some consistency emerged, there were variations by age categories. The five most highly rated states for junior athletes during their best performances included motor behaviour functional, volitional functional, bodily functional, cognitive functional and motivational functional (See Table 2). The five highest rated states for adolescents were bodily functional, cognitive functional, emotional anger functional, volitional functional, and motivational functional. The five for adults were cognitive functional, motivational functional, emotional affection functional, volitional functional, and bodily functional. On the worst performance, junior athletes rated bodily dysfunctional, operational dysfunctional, motor behavioural dysfunctional, emotional anxiety functional and emotional anger dysfunctional. The five most chosen states for adolescents during were emotional anger dysfunctional, cognitive dysfunctional, motor behavioural dysfunctional, operational dysfunctional, and bodily dysfunctional. For adults the five highest rated states included emotional anxiety functional, cognitive dysfunctional motor behavioural dysfunctional, operational dysfunctional, and bodily dysfunctional.

Table 2.

*Five psychobiosocial states during performances – by age (M=mean; SD=standard deviation)*

Juniors		Adolescents		Adults	
<u>Best Performance</u>	<u>Worst Performance</u>	<u>Best Performance</u>	<u>Worst Performance</u>	<u>Best Performance</u>	<u>Worst Performance</u>
Motor behavioral functional (M=3.50, SD=.68)	Bodily dysfunctional (M=3.06, SD=1.14)	Bodily functional (M=3.63, SD=.49)	Emotional anger dysfunctional (M=3.1, SD=1.01)	Cognitive functional (M=3.41, Sd=.67)	Emotional anxiety functional (M=3.09, SD=1.01)
Volitional functional (M=3.43, SD=.57)	Operational dysfunctional (M=3.06, SD=.94)	Cognitive functional (M=3.56, SD=.50)	Cognitive dysfunctional (M=3.03, SD=.808)	Motivation functional (M=3.32, SD= .65)	Cognitive dysfunctional (M=3.03, SD=.87)

Bodily functional (M=3.40, SD= .72)	Motor behavioural dysfunctional (M=3.06, SD=1.01)	Emotional Anger functional (M=3.55, SD=.57)	Motor behavioural dysfunctional (M=2.93, SD=1.11)	Emotional Affection functional (M=3.32, SD=.72)	Motor behavioural dysfunctional (M=2.93, SD=.99)
Cognitive functional (M=3.23, SD= .77)	Emotional anxiety functional (M=2.87, SD=1.04)	Volitional functional (M=3.26, SD=1.04)	Operational dysfunctional (M=2.86, Sd=1.07)	Volitional functional (M=3.29, SD=.78)	Operational dysfunctional (M=2.84, Sd=.87)
Motivational functional (M=3.23, SD= .77)	Emotional Anger dysfunctional (M=2.80, SD=1.18)	Motivational functional (M=3.13, SD=1.10)	Bodily dysfunctional (M=2.72, SD=1.16)	Bodily functional (M=3.22, SD=.99)	Bodily dysfunctional (M=2.58, SD=1.31)

The analysis found significant differences among the three age groups in their PBS-ST total score during their best performance ( $F(2,86) = 5.6$ ,  $p < .01$ ). Table 3 shows that juniors experienced higher intensity of their psychobiosocial states during their best performance than their adolescent and adult counterparts. Differences between juniors/adolescents and junior/adults ( $p < .01$ ) were

statistically significant. However the differences between adolescents and adults' PBS-ST in their best performance were not statistically significant. Additionally there were no statistically significant differences in PBS-ST total score on self-reported worst performance.

Table 3.  
*Age differences in PBS-ST total score by performances*

		N	Mean	Standard deviation
<b>Best performance</b>	Juniors**	30	42.63	8.15
	Adolescents	28	38.85	6.53
	Adults	31	35.74	5.42
<b>Worst performance</b>	Juniors	30	36.90	4.41
	Adolescents	28	34.42	7.21
	Adults	26	35.42	6.54

Note: \*\* $p < .01$

ANOVA was performed to examine each state impact on performances across each group. There were age significant differences in 9 states including emotional anger functional ( $F=3.23$ ,  $p=.044$ ), cognitive dysfunctional ( $F=4.37$ ,  $p=.015$ ), communicative dysfunctional ( $F=6.17$ ,  $p=.003$ ), emotional anxiety

functional ( $F=5.02$ ,  $p=.009$ ), motor behavioural dysfunctional ( $F=15.79$ ,  $p=.000$ ), motivational dysfunctional ( $F=15.36$ ,  $p=.000$ ), emotional anxiety dysfunctional ( $F=8.87$ ,  $p=.000$ ), emotional anger dysfunctional ( $F=8.49$ ,  $p=.000$ ), volitional dysfunctional ( $F=4.9$ ,  $p=.009$ ). Table 4 shows the

means, standard deviations, significant difference between juniors, adolescents and adults by state.

Table 4.  
*Age differences on psychobiosocial status*

PBS-ST	Junior		Adolescent		Adults	
	Mean	SD	Mean	SD	Mean	SD
Emotional Anger Functional *	2.96	1.06	3.55	0.57	3.19	0.94
Emotional Anxiety Functional **	1.46	1.45	0.93	1.17	0.51	0.81
Emotional Anger Dysfunctional **	0.80	0.80	1.43	1.33	0.38	0.76
Emotional Anxiety Dysfunctional **	1.73	1.63	0.60	0.72	0.67	0.94
Cognitive Dysfunctional *	1.06	1.12	0.83	0.94	0.61	0.11
Communicative Dysfunctional **	0.93	0.98	0.60	0.81	0.22	0.08
Motor Behavioural Dysfunctional **	1.13	0.77	0.16	0.37	0.38	0.84
Motivational Dysfunctional **	0.63	0.66	0.06	0.25	0.09	0.30
Volitional Dysfunctional **	0.73	1.14	0.10	0.30	0.32	0.70
<b><u>Worst Performance</u></b>						
Cognitive function **	1.6	.93	.60	.78	1.07	.84
Communicative function*	.93	.82	.42	.69	1.0	.97
Volitional function **	1.36	.92	.57	.87	1.23	.86
Emotional anger dysfunctional**	2.80	1.18	3.10	1.03	1.76	1.17

Note: \* $p < .05$ ; \*\* $p < .01$

Although there are age differences found in 9 PBS-STs, the distributions are not consistent. Most of the differences are found in between juniors/adolescents and junior/adults. Juniors and adolescents report significantly different scores on emotional anger functional and volitional dysfunctional during their perceived best performance. Juniors stated stronger feelings toward cognitive dysfunctional, communicative dysfunctional, emotional anxiety

functional, and emotional anger dysfunctional when compared with adult players. Juniors reported higher intensity toward motor behavioural dysfunctional, and motivational dysfunctional when compared to both adolescents and adults. Overall, juniors experienced stronger dysfunctional states during their best performance than adolescents and adults (See Figure 2).

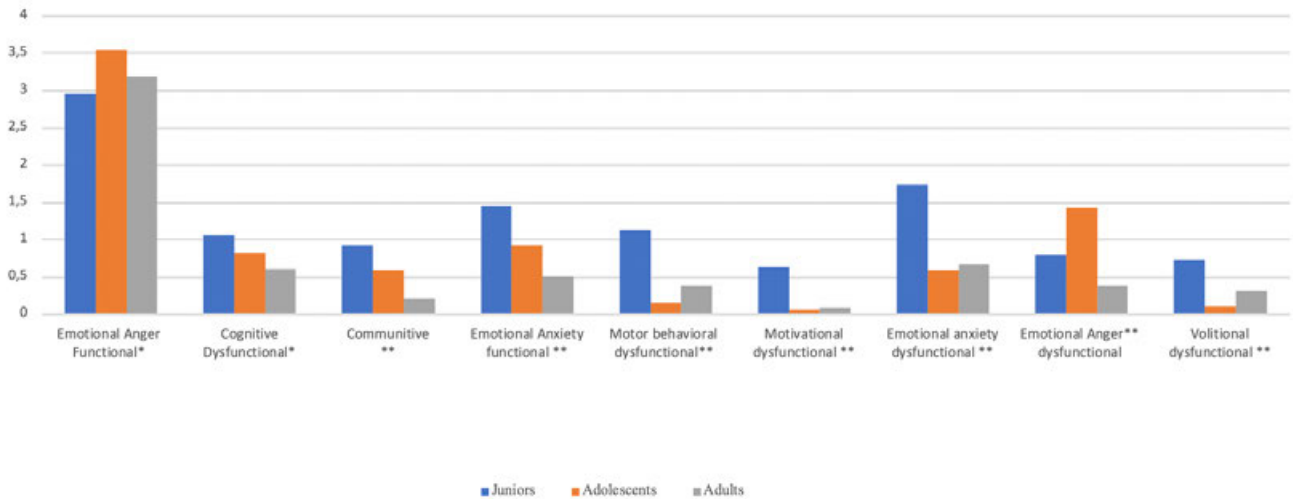


Figure 2. Differences of psychobiosocial states by age according to their best performance.

While there were no overall differences during worst performance, some differences emerged by functional component. For example, there were significant differences in cognitive functional, communicative functional, volitional functional, and emotional anger dysfunctional. Figure 3 shows higher levels of intensity in cognitive functional and volitional functional in juniors compared to

adolescents, but no differences when compared to adults. Adolescents and adults felt differently in communicative functional and volitional functional. Compared to their adult counterparts, juniors and adolescents reported stronger feeling in emotional anger dysfunctional during their perceived worst performance.

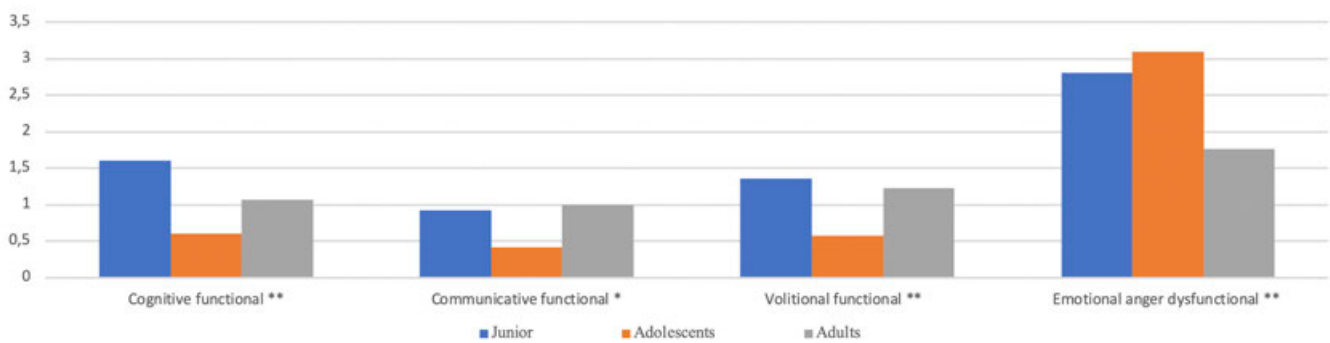


Figure 3. Differences on psychobiosocial states by age according to their worst performance

## Discussion

The purpose of this study was to identify the intensity of psychobiosocial states in competitive badminton players' self-reported best and worst performance at USAB sanctioned tournament. The study also examined the extent to which development, as defined by age group, impacts

athletes' perceptions of play. The results confirmed previous studies showing that emotion affects performance in competitive sports. While this comes as no surprise to those who compete in competitive sports, the study provides a deeper, more nuanced understanding of eight psychobiosocial states. The eight psychobiosocial states (cognitive, emotional, motivational, bodily, communication, operational, motor behavioural and volitional), and athlete's

ability to identify and regulate them influence player's perceived quality of performance. The cross-sectional study showed differences by age range on the total scale score as well as within and between various components. Adult participants reported higher intensity of cognitive and emotional state during both their best and worst performance. Juniors' consistently perceived stronger intensity in physical actions (bodily and motor behavioural) during both best and worst performance. During their worst performance, physical and negative emotional anxiety dominated juniors' states. They were less likely to focus on cognition functions such as information processing and strategic planning. The findings echo the classic Piaget's theory stages of cognitive development that suggests that children under 12 in the stage of concrete operational experiences with the environment focus on what they see in front of them. Adolescents, especially older adolescents, and adults entering higher levels of cognition possess the ability to think more abstractly. This was consistent with their intensity on more cognitive than physical reactions. Unlike their junior and adult counterparts, a unique emotion emerged in adolescents. Adolescent emotions were more consistent with anger rather than anxiety/affection in both best and worst performances. Anger was presented as both facilitator and inhibitor during the competitions. Besides the dysfunctional emotion anger, adolescent and adult participants experienced very similar psychobiosocial states during their worst performance.

During their best performance, junior participants experienced significantly more intense, higher overall total scores. Compared with juniors, later adolescents were similar to adults in their cognitive, emotional and physical states. The intensity of states was more pronounced in juniors, with higher mean scores on 8 out of 20 states as compared to their adults and adolescent counterparts. Adult and adolescent did not experience as many dysfunctional states as junior participants. The one exception was in the emotional anger function. Adolescents counted on the emotional anger, such as fighting, spirit, fierce, aggressive, to facilitate their

performance more than juniors and adults reported. Adolescent's perception of the matches, especially the perception of emotional anger, echoed Stanly Hall (1904) characterized adolescents as a time of "storm and strife". Anger presented as drive and damage to adolescents' performance (Arnett, 2006). When compared to adolescents and adults, juniors experienced a higher level of anxiety (both functional or dysfunctional) during their best performance. This is most likely associated with their lack of experiences or immaterial brain development, causing inaccurate evaluation during intensive competition. The uncertainty produces elevated anxiety during the match. It is reasonable to find a higher anxiety level in juniors than in adolescents and adults, especially in the winning condition.

When evaluating their worst performance, participants' overall psychobiosocial states were similar across all age groups. Adolescents presented less intensive mental states compared to juniors and adults participants in cognitive, communication, and volition. Negative emotional anger was found in juniors and adolescents mental states, but this had less impact on adults' performance. Some similarities across age groups were found, primarily in their reflection on their worst performances. They all reported experiencing negative physical reactions. Secondly, drive (motivation and volition) were in the top 5 states in their best performances. Third, the top 5 states reported in best performances were functional, while the top 5 states in worst performances were dysfunctional. This finding echoed the ZOF model, where positive states facilitate the performances, and negative states work against athlete's performance.

### *Implications for theory and practice*

The findings from this study have theoretical implications from both ZOF model and developmental psychology. Not all psychobiosocial states were perceived similarly across all age players. Future longitudinal studies could examine if developmental differences emerge in a set of players as the progress from juniors to adolescents to adults in competitive badminton. To promote the most

optimal results during a match in a split second, coaches need to understand that players of different ages perceive and experience various psychobiosocial states differently during matches. With unique physical, cognitive and psychosocial developmental status, a player experiences three distinguished stages within their own growth. Coaches who are sensitive to limitations of regulating particular states can discuss how the player is reacting in real time to a particular drill or practice match. The conversation can help the player articulate their psychobiosocial state, in their own words, and the coach can help them with strategies to identify and react the next time the player feels a similar way. They can create signs and talking points that can translate to how to coach during competitive badminton matches. This is particularly salient when players express anger. During the interval, coaches can refocus the player and give them reminders of how to regulate the feelings during the next several points. Additionally, after matches, players can reflect on how they reacted to various states during the match. To move in this direction, additional professional development for coaches psychobiosocial states can be incorporated into coach credentialing.

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