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ORIGINAL

DETERMINING PRE-CUES IN PADDLE TENNIS BY USING A KINEMATIC ANALYSIS

DETERMINACIÓN DE PREÍNDICES EN PADEL MEDIANTE ANÁLISIS CINEMÁTICO

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ABSTRACT

Using a kinematic analysis, this study aims to find out the existence of visual signals (pre-cues) in drive strokes made from the back of the court after the ball hits a wall, considering each possible direction (right, centre and left). Five expert paddle tennis players took part in the study. The body areas that could be most useful to the defensive player as informative pre-cues ($r=,896$ $p<,001$ y $r=,777$ $p<,001$) were those related to the hand height and the position of the left heel, at the beginning and at the end of the movement. These data confirm the existence of three movement patterns according to the chosen direction (maximum hand height and most open left heel angle in relation to the transverse plane of the body when the ball goes to the left half of the court, with the striking player as reference).

KEYWORDS: pre-cues, paddle tennis, biomechanical analysis

RESUMEN

El objetivo es determinar la existencia de indicadores visuales (preíndices) en el golpe de derecha desde el fondo de pista tras rebote en pared en padel para cada una de las posibles direcciones (derecha, centro e izquierda) mediante análisis cinemático. Han participado en el estudio cinco jugadores expertos de padel. Los valores encontrados para altura de la mano y la posición del talón izquierdo en el momento de inicio y final del movimiento se revelan como las zonas corporales que más información podrían proporcionar como pre-índices informacionales para el jugador en defensa ($r=,896$, $p<,001$ y $r=,777$, $p<,001$). Los datos confirman la existencia de tres patrones de movimiento en virtud de la dirección elegida (máxima altura de la mano y mayor ángulo del talón izquierdo respecto al plano transversal del cuerpo cuando la bola se dirige a la parte izquierda de la cancha, tomado como referencia el jugador que golpea).

PALABRAS CLAVES: Preíndices, padel, análisis biomecánico

INTRODUCTION

The skill to predict an opponent's actions is highly relevant for the performance in several sports, especially when uncertainty and time-space restrictions are relevant factors (Williams, Ford, Eccles, & Ward, 2010a).

Paddle tennis is a racket sport classified as an open-skills sport, in which players must make constant and short-term decisions from the different options available in each game situation, and under time pressure, due to the ball trajectory and speed. As a consequence, decisions have to be made very quickly.

Paddle tennis could be described as a merge of tennis and squash, with a score system very similar to that used in tennis and several customised rules; for example, serve must be underhand (stroke at hip level, maximum) and players can strike the ball after it hits any wall (and before the ball bounces in the court for a second time).

The court measures 20 metres long by 10 metres wide, and it is divided by a 0,88 m-high net, resulting in two equal halves of 10 m x 10 m. Side and back walls (made of methacrylate in standard courts) are 3 metres high (see Figure 1).

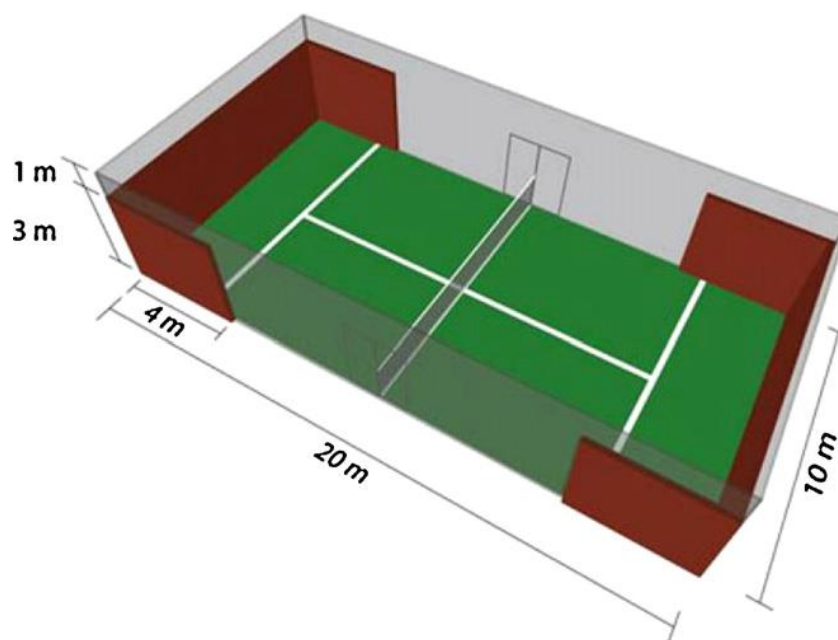


Figure 1. Dimensions of the paddle tennis court

Paddle tennis strokes can be classified in three groups: direct strokes, indirect strokes (after the ball hits the walls) and services.

According to a study by González (2006), indirect strokes come to 31,8% of total strokes, of which forehand strokes amount to 20,16%. Carrasco, Romero, Sañudo, and de Hoyo, (2011) found that most frequent direct stroke used during the games analyzed was volley (25.57% of the total strokes performed). At a lower frequency, they appreciated backhand (15.57%), over- head or smash (12.45%), and forehand (11.80%). Finally, the lob was the less used stroke during paddle tennis competition (2.95%). In regard to boast or indirect strokes, the forehand was the most used stroke (20.16%), while the backhand showed a frequency of 8.36%. The lob was the indirect stroke less used, accounting only for frequencies of 1.80 of the total indirect strokes performed, respectively.

The most frequent action in this group was striking the ball after it hit the back wall –a highly significant fact, since the frequency of the strokes helps to understand their technical and tactical relevance during the game, as well as their influence on the outcome (Blompvist, Luhtanen, & Laakso, 1998).

Aiming to confirm these data and justify the development of this study, we made a quantitative analysis of the strokes during the final match in an international paddle tennis tournament (III International Tournament Ciudad de Melilla), played by the best four players in the global ranking. The most frequent indirect stroke was hitting the ball after it bounded the back wall of the court (52 strokes during the match, 36% to the right of the striking player, 49% to the centre of the court, and 15% to the left of the striking player).

Perceptual anticipation in sports

Anticipation is a valuable skill in sports. Several studies support that one of the factors explaining the better performance showed by expert players –compared to novices– is the skill to anticipate their opponents' behaviour.

People are able to predict future events by observing others' actions. This skill has been widely studied in the sports level. In racquet sports, expert players can successfully predict their opponents' intentions before they perform key events, such as the racquet-ball contact (Williams, Ward, Knowles, & Smeeton, 2002).

According to some authors, the anticipation comes as a result of the dynamic interaction between many perceptual-cognitive skills (Williams, Ford, Eccles, & Ward, 2011). These include the ability to identify structures and known elements in game sequences (North, Ward, Ericsson, & Williams, 2011), but also the skill to draw anticipation signals while an opponent is preparing his/her movement (Abernethy, Zawi, & Jackson, 2008).

The ability to predict an opponent's action has been investigated by using different models; according to the same studies, this anticipation skill is particularly (but not only) implemented when the player analyses and discriminates the information of movement pre-cues (Williamt & Grant, 1999). The use of pre-cues refers to a sportsman's skill to do accurate predictions based on the contextual information available from the initial stage of an action sequence (Abernethy, 1987). This theoretical point of view differs from the theory suggesting that expert sportsmen are able to use the situational expectations or probabilities to ease anticipation in sports; that is, they have the possibility to use their higher knowledge as a base to dismiss certain events as being highly improbable, and they can also establish a hierarchy of probabilities for the remaining events (Granda & Alemany, 2002:160).

As far as racket sports (such as paddle tennis) are concerned, researches have focused on the different ways in which players use the pre-cues while observing their opponents, in order to have enough time to move across the court, reach the interception point and strike the ball back. The prediction of the ball trajectory after an opponent's strike is based, in most cases, on data drawn from events that take place before the opponent actually strikes the ball (Abernethy, Gill, Parks, & Packer, 2001; Williams, Ward, Knowles, & Smeeton, 2002). We should point out that in paddle tennis, the distance between the opponents is shorter (a court with smaller dimensions) than in tennis, placing a higher relevance on the perceptual anticipation skill of the defensive player and its influence in the subsequent decision making event.

In this sports group, the ball usually reaches high speeds, so the main task of a defensive player is predicting, as soon as possible, the trajectory and height of the ball sent by the opponent. This is due to the fact that, in many open-skills sports (high uncertainty level in decision-making/response) (Granda, Mingorance, Barbero, Hinojo, Mohamed, & Reyes, 2008; Núñez, Oña, Bilbao, &

Raya, 2005; Hernández, Ureña, Bilbao, & Oña, 2003), determining the signals or pre-cues that allow a player to know in advance his/her opponent's movement (with the subsequent increase in motor response time) is a key factor influencing sports performance.

At this respect, the possibility of anticipating a movement depends on the existence of verifiable differences between features that remain invariant during a certain stroke (such as the stroke analysed in this study). Accordingly, Troje (2002) and Westhoff and Troje (2007) suggest that the dynamic features of a movement are more relevant than the anatomic ones when predicting the opponent's ball trajectory and height.

In this regard, researches on racket sports show that, due to the time pressure, collecting data about the opponent's movement pattern is crucial for an expert performance (Glencross & Cibich 1977). There are at least two main information sources available that make the anticipation easier for the executing player: (i) specific data drawn from the movement pattern before the opponent strikes the ball with the racket, and (ii) general information regarding situational probabilities, given the specific frame in which the opponent makes the stroke. The evidence to date regarding racket sports suggests a strong link between expertise and the skill of collecting information about the kinematics of an opponent's action. On one hand, expert players use the most proximal sources of information during the action (arm and racket position). This fact is in line with the idea that expert players' advantage is based on a higher skill to analyse the proximodistal kinematic development of the action they are observing. On the other, several studies comparing visual strategies of expert and novice players found out that expert players fix their eyes on head, trunk and hip areas, while novice players stare at the racket position (Ward, Williams, & Bennett, 2002). The same authors highlight the different ways to use kinematic information as another main difference between expert and novice players.

These findings confirm that the time structure of ball strokes in tennis (exactly the same in paddle tennis) informs the opponent about the next spatial position of the ball, but it does not explain how this information is reflected in the movement patterns (Huys, Smeeton, Hodges, Beek, & Williams, 2008).

Implementation of the biomechanical analysis in the study of perceptual anticipation

Technological advances in recent years allowed developing in-depth three-dimensional kinematic analyses on ball strokes using a racket. Thanks to these biomechanical methods, it was possible to research the procedures underlying the execution of skills involved in a racket stroke (Lees, 2003).

Data regarding the angular values of the relevant joints, linear and angular speeds and ball speed during tennis services (Elliott, Marsh, & Blanksby, 1986; Papadopoulis, Emmanouilidou, & Prassas, 2000), tennis forehand (Elliott, Marsh, & Overheu, 1989a), tennis drive (Elliott, Marsh, & Overheu, 1989b) and

tennis volley (Elliott, Overheu, & Marsh, 1988) were determined using the techniques for three-dimensional analyses of racket skills.

The kinematics of all the strokes in racket sports follow a predictable proximodistal sequence when registering the segments involved in the action: it starts with a step ahead of the contralateral leg, followed by the hip movement and the trunk rotation, and then by the segment movements of, in order, the upper arm, the forearm and the hand (Elliott et al., 1986; Woo & Chapman 1991).

In a study involving an expert tennis player, Ward et al., (2002) found differences in the movement patterns of the different tennis strokes, including changes of parameters, such as the maximum values of the relevant joints angles, although the differences showed by the analysed parameters on the basis of the ball direction were minimal.

Movement patterns found through the kinematic analysis can be break down into several structures or components. According to Troje (2012), walk patterns in men and women could be break down into four rhythmical components by subjecting their main components to a factor analysis.

Huys, Smeeton, Hodges, Beek and Williams (2008) used a methodology very similar to Troje's when studying the performance of strokes in tennis with different directions. They found underlying dynamic structures in the performance and concluded that every body area helped to generate these structures, with minor variations among the strokes regarding the freedom of movement.

Based in these findings, Huys, Cañal-Bruland, Hagemann, Beek and Smeeton (2009) analysed the importance of the information drawn from certain dynamic structures (racquet, shoulders, hips and legs) when the players try to predict the direction of strokes in tennis through the visual occlusion method. The results showed that the players could predict the direction of more strokes when having a global perceptive approach than more local structures, especially those players with higher skills or expertise.

Alonso and Argudo (2011) carried out a notational analysis on the performance of Olympic frontenis service. The results showed that it was more effective when the player moved to the right. Moreover, the most difficult services to return were the backspin services directed to the lateral wall 3, although they were not the most common ones.

Based on previous related researches, and using a three-dimensional kinematic analysis, this study aims to find out kinematic patterns in the movement sequence of a specific stroke in paddle tennis. To this end, we analysed drive strokes made from the back of the court after the ball hits a wall, considering each possible direction of the ball (right, centre and left). Once determined, the patterns were evaluated to establish if they could be pre-cues applicable to the training and improvement of the perceptual anticipation skill in defensive responses during real game situations.

METHOD

Participants

Five elite paddle tennis players took part in the study (see table 1).

Table 1. *Features of the participants in the study*

	Category/Ranking	Sex	Age	Height	Weight
Participant 1	International/World champion	M	32	176 cm	75 kg
Participant 2	International/World second place	M	30	177 cm	74 kg
Participant 3	National/8th national ranking	F	24	178 cm	73 kg
Participant 4	National/7th national ranking	M	25	172 cm	68 kg
Participant 5	National/12th national ranking	M	23	175 cm	72 kg

All participants were previously informed about the purpose and aims of the study, and they gave their consent to register and analyse the data included in this paper.

Material

Three cameras Casio EXF1 were used to record the participants' strokes. We used the software Kinescan (IBV) version 8.3 to digitalize and make a kinematic analysis of movements.

Procedure

Once the players were properly informed and they gave their consent to take part in the study, we proceeded recording the strokes in a public standard paddle tennis court.

We had previously registered a reference system: a structure of known geometry and dimensions, which support several markers placed on fix and accurately known points. The structure was a cube-shaped system of 2 x 2 x 2 m.

We used three video cameras filming at 250 fps (frames per second). Two cameras were placed with the optical axis at a 90°-100° angle, so as many as possible of the markers could be clearly seen, and the subsequent digitalization could be easier. The third camera was placed in the middle of the court, on the front of the participants' position, so it could record the ball direction.

Pictures were digitally recorded and converted in AVI files, which were then used in the digitalising process.

Once the reference system had been filmed, one of the participant players positioned himself at the geometrical centre of his field (a court half) and an assistant player threw a ball from the opposite field (lob). After the ball bounced in the court, it had to hit the back wall, while the participant player moved

backwards to approach the wall and make the previously described drive stroke. The player should randomly and freely choose the ball direction (right, centre or left). An auxiliary camera recorded the stroke from a front point of view to register the direction, and subsequently link the kinematic values (movement patterns) with the ball direction.

The participants made 50 replays of the analysed action. Of the recorded actions (350), 72 were considered suitable for the study, after three expert paddle tennis trainers had described them as expertly performed actions.

The technique used to collect data was the 3D video photogrammetry. It gets the coordinates of a specific point, by simultaneously filming the event with two or more cameras and processing the images.

Once the actions were filmed, we digitalized the data. This process consisted of four stages: calibration, scene digitalization, smoothing of coordinates and getting to outcomes, and graphs management.

We used the mechanical model suggested by Clauser, McConville, and Young (1969) and Zatsiorsky, Seluyanov, and Chugunova (1990). In each frame, 25 points (system + tool) were manually digitalized, that is, a “system and tool” scheme consisting of the player with the paddle and the ball. The inertial corporal parameters were taken from De Leva (1996) and the outcomes were filtered using fifth-order spline functions (Woltring, 1985).

The study variables were of two kinds: spatial (striking hand height, distance between feet –measured on the heels– and position of right and left heels) and angular (angles of right hip and right and left knees), at the beginning of the movement and at the moment of the stroke. One observer was responsible for data encoding. The reliability of the register was ensured by randomly selecting 5 strokes from the set of valid strokes, registered by the observer on two occasions (with an interval of a week; the values of the first register were unknown when we proceeded with the second register). The intraobserver reliability value reached 98%.

After getting the concurrent kinematic values for each direction, as well as the links between the different corporal segments, we watched two paddle tennis matches (finals of international tournaments, involving the 4 world’s best players) in order to determine the correspondence between the findings of the kinematic analysis and the real game actions.

Data analysis

In the data analysis we used the statistical pack SPSS V.20. The values were subjected to the test of Pearson’s correlation in search of links between them, aiming to subsequently develop a regression analysis. The selected method was the linear regression model, since it was the most suitable method for this data structure (after comparing between different models in this statistics).

RESULTS

Table 2 shows the descriptive values for the study variables at the beginning of the action (maximal rotation of the striking hand against the striking direction) and at the end of the action (contact between paddle and ball) found in the set of analysed valid strokes.

Table 2. Description of the study variables

	Mean	SD
Distance between heels – beginning (dishelb)	0.59	0.11
Distance between heels – end (dishele)	0.63	0.11
Striking hand height – beginning (strhanheib)	2.42	0.33
Striking hand height – end (strhanheie)	2.32	0.37
Left heel – beginning (lefthelb)	1.96	0.44
Left heel – end (lefthele)	1.97	0.43
Right heel – beginning (righelb)	1.78	0.41
Right heel – end (righel)	1.76	0.41
Left knee angle – beginning (leftknangb)	141.24	46.94
Left knee angle – end (leftknange)	145.70	37.89
Right knee angle – beginning (rigknangb)	156.25	6.88
Right knee angle – end (rigknange)	161.97	10.59
Right hip angle – beginning (righipangb)	140.56	7.53
Right hip angle – end (righipange)	144.51	10.86

Table 3 shows the values found after applying the Pearson’s R statistic to the data.

Table 3. Values showing significant correlations between the study variables

	dishel e	lefthelb	lefthele	righel e	leftknang e	rigknang e	righipangb	righipange
dishelb	0.698 0.000							
strhanheib		0.896 0.000	0.891 0.000					
strhanheie		0.778 0.000	0.777 0.000					
lefthelb			0.988 0.000					
righelb				0.997 0.000				
leftknangb					0.953 0.000			
rigknangb						0.652 0.000	0.418 0.022	0.418 0.022
righipangb								0.584 0.001

According to data in table 3, there are significant links between the variables regarding the spatial positions, and between the angular variables. However, there were no strong links between any of the spatial and angular variables.

Given that considering angular values as pre-cues is highly complex in real game situations, and since there were not links between these values and the spatial variable values, we only used the linear regression analysis with the spatial variable values. The results of this analysis are in table 4.

Table 4. Values from linear regression

Predicting Variable	Dependent Variable	R	R squared	F	Sig.
Striking hand height – beginning	Left heel – beginning	0.896	0.803	113.83	.000
Striking hand height – beginning	Left heel – end	0.891	0.793	107.51	.000
Striking hand height – end	Left heel – end	0.777	0.604	42.66	.000
Left heel – beginning	Striking hand height – end	0.778	0.605	42.82	.000

DISCUSSION

This study aims to determine a specific motor (kinematic) pattern for each possible ball direction in a paddle tennis stroke, by using three-dimensional techniques, in order to apply the findings to the training and make the anticipation easier for a defensive player in this context.

Of the analysed data, the body areas that could be most useful as informative pre-cues by the defensive player were those related to the hand height and the position of the left heel, at the beginning and at the end of the movement. The link between these areas is highly relevant among the values shown by both variables at the beginning and at the end of the action (see figures 2, 3 and 4).

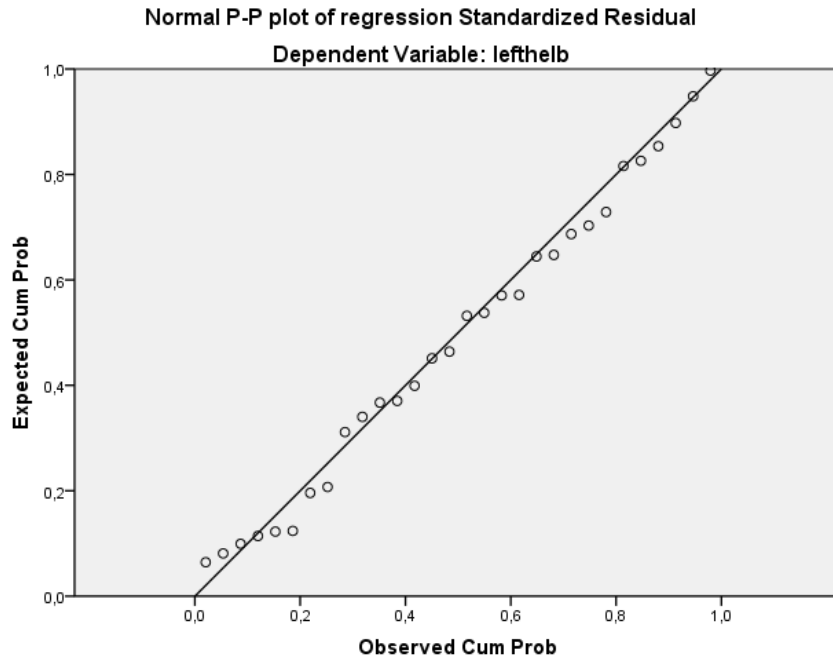


Figure 2. Chart showing the values drawn from the linear regression of variables “striking hand height – beginning” (strhanheib) and “left heel position – beginning” (lefthelb)

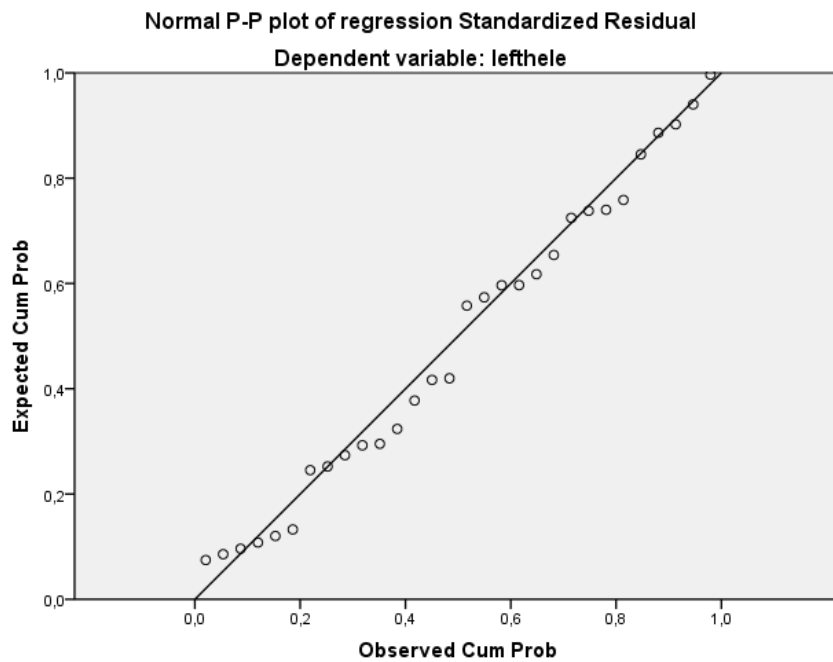


Figure 3. Chart showing the values drawn from the linear regression of variables “striking hand height – end” (strhanheie) and “left heel position – end” (lefthele)

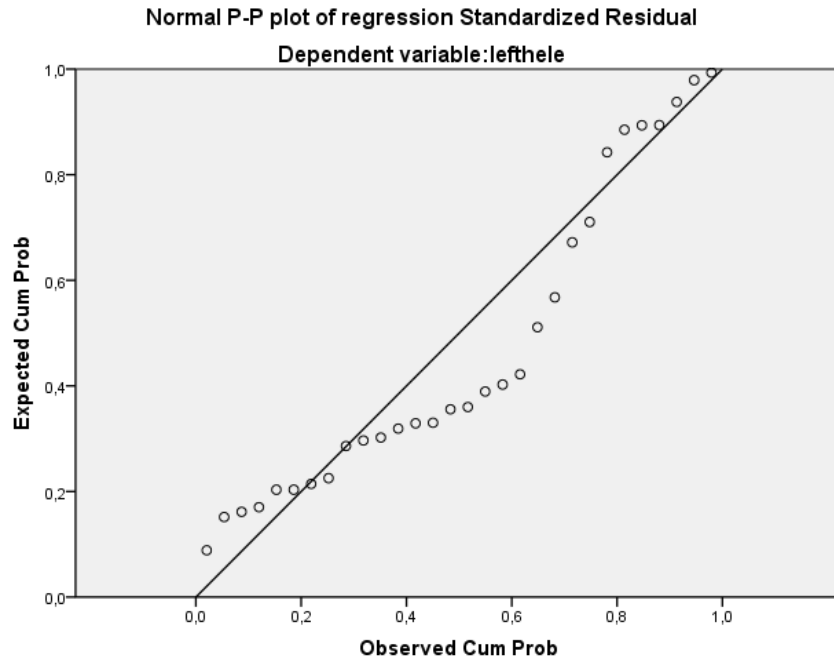


Figure 4. Chart showing the values drawn from the linear regression of variables “striking hand height – beginning” (strhanheib) and “left heel position – end” (leftthele)

The data confirm the existence of three movement patterns in each variable according to the striking player’s decision on the ball direction, applying different starting points to the study variables based on the selected direction. This allowed proving that the higher the hand is placed when striking the ball, the farther the left foot (heel) is placed (open angle) (ball direction to the left of the striking player) in relation to the longitudinal axis of the court; a lower height is related to closer positional values of the left heel (close angle) in relation to that longitudinal axe (see figure 5) (ball direction to the right of the striking player). For strokes directed to the centre of the court, it has been checked that the left heel was placed over the longitudinal axe of the player. These results match those by Ward et al. who, (2002) in a study involving an expert tennis player, found differences in the movement patterns of the different tennis strokes.

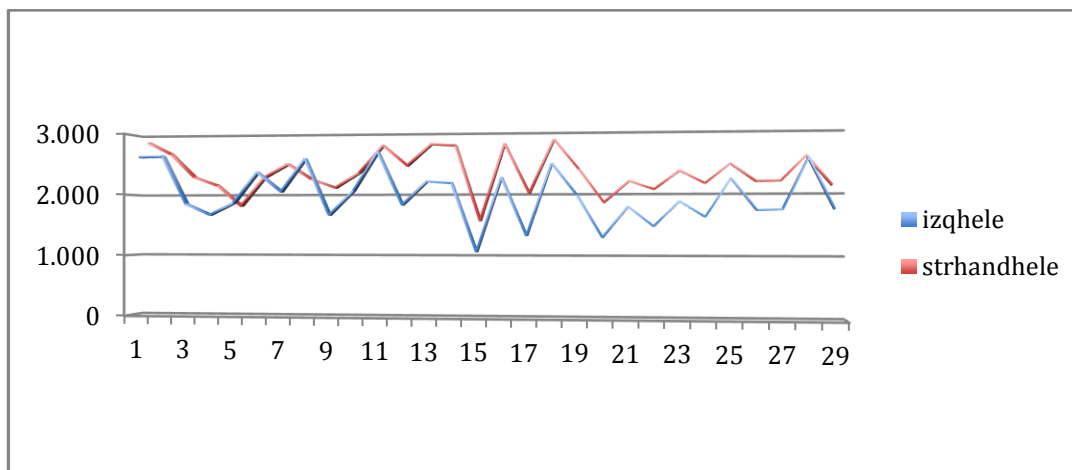


Figure 5. Values from the striking hand height and the left heel at the moment of the stroke

According to evidences in racquet sports to date, expert players use the most proximal sources of information during their performance (arm and information about the racquet position). This is consistent to the notion that their advantage is due to a higher ability when assessing the proximal-distal kinematic evolution of the observed action (Elliott et al., 1986; Woo and Chapman 1991). The proximal-distal relation (racquet-left foot) is confirmed in this striking action, suggesting that it can be relevant information to improve the anticipatory skill of the defensive player in similar situations.

This finding would help to introduce learning situations that could improve the use of perceptual-cognitive skills by paddle tennis players during their learning process. These skills include the ability to identify structures and known elements in game sequences (North, Ward, Ericsson, & Williams, 2011), and allow them to draw pre-cues while their opponent is preparing a movement (Abernethy, Zawi, & Jackson, 2008).

The results found in this study match also the findings of Huys et al. (2009). They pointed out the importance of the information drawn from certain dynamic structures (racquet, shoulders, hips and legs) when the players try to anticipate the direction of strokes in tennis through the visual occlusion method. Aiming to establish the ecological value of these findings, we analysed two paddle tennis matches (top-level, international tournament finals - Torneos Internacional de Melilla 2007 y 2008), involving the 2 world's best pairs. We found 106 situations in which the ball was stroke after hitting a wall. Of them, in 40 situations (37.22%) the ball was directed to the right of the opponent's field (from the striking player's point of view), in 50 situations (47.1%) the ball was directed to the centre, and in 12 situations (16%) the ball was directed to the left of the field.

In 89% of the registered situations, the players showed the previously mentioned pattern, according to the direction of the ball after the stroke (see figures 6, 7 and 8). In the rest of the situations (11%), the players broke this kinematic-direction link of the ball using actions typical of highly expert subjects, which allow them to do actions different to the kinematically accurate model.

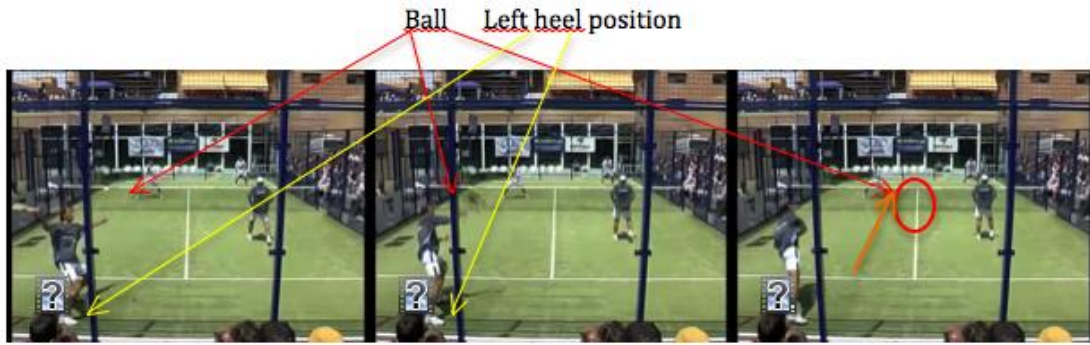


Figure 6. Sequence "stroke-ball direction-centre court side" (striking player's point of view)

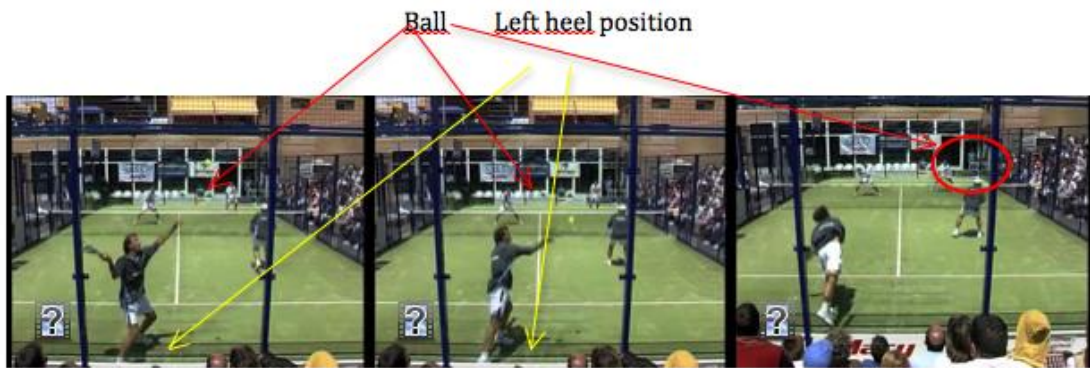


Figure 7. Sequence "stroke-ball direction-right court side" (striking player's point of view)

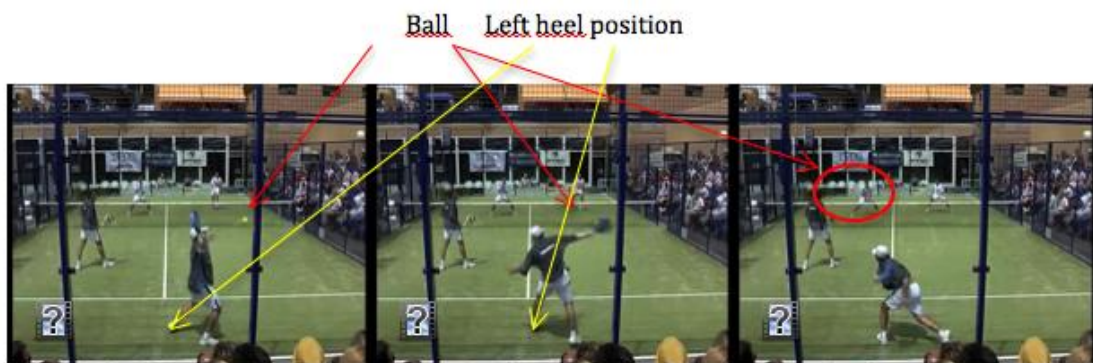


Figure 8. Sequence "stroke-ball direction-left court side" (striking player's point of view)

To sum it up, the use of the kinematic analysis to prove the existence of movement information (anticipation signals) in open sports situations –which could be later included in learning processes aimed to novice players– is a very useful tool to determine the cues that provide both an easier anticipative response, and a faster and more effective performance in real game situations.

The results **encontrados parecen** confirm the existence of dynamic differences in the striking patterns according to the ball direction, so they can be used to improve the perceptive anticipation skill of paddle tennis players. This anticipation skill depends on confirming differences between features that remain constant during the performance of a stroke (Troje, 2002; Westhoff and Troje, 2007).

Based on these findings, it would be necessary to go further with these studies made from the defensive player's point of view, in order to determine if players use the movement pre-cues found in this research to anticipate the ball direction, thus taking an advantage when responding in real game situations.

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