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Perturbations created from the baseline in tennis: a test of barker's behaviour setting theory

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The purpose of this study was to characterise perturbations created from the baseline in men's tennis following Barker's ecological psychology approach. In selected rallies of expert level tennis matches we identified the shot responsible for this perturbation and characterised it using a sequential approach based on the positioning of the players in the court, the technical actions used by both players, and the displacements that each player forced on the opponent. Results reveal specific patterns of player behaviour and types of displacement in response to the opponent. Moreover, we found significant variability of the technical actions and action zones expressed during the perturbation processes. These results suggest that perturbation behaviours are constrained by the 'behaviour setting', which allows individuality during the search for effective solutions to achieve a specific goal. This test of Barker's behaviour setting theory in sport offers a principled guidance for coaches embed psychology into task design for practice sessions.

KEY WORDS: Action zones in tennis, Barker's ecological psychology, Behaviour mapping, Perturbations in tennis; Sequential analysis.

Introduction

The concept of 'perturbation' during a game has been investigated in soccer, squash and, more recently, in tennis. In squash, McGarry and Franks (1996) and McGarry, Khan and Franks (1999) defined perturbation as a shot that changes a relatively stable rally, creating an obvious situation of advan-

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tage to one of the players. The results of these studies verified that shots causing perturbations can be identified in a reliable way by independent expert observers. Hughes and Reed (2005) describe perturbations in soccer as "an incident that changes the rhythmic flow of attacking and defending" (p. 35), and these authors, by means of notational analysis, were able to identify perturbations and characterized them relatively to some technical actions and zones of the pitch used by the players. Hughes and Reed (2005) conclude that teams can be distinguished by the ways that they use to create opportunities to score goals. These authors set the basis for the theoretical concept of perturbation, which was therefore operationalized in sport sciences. The definition of perturbation in tennis by Carvalho and collaborators (Carvalho, Araújo, Travassos, Esteves, et al., 2014; Carvalho, Araújo, Travassos, Fernandes, et al., 2013) is similar to that of squash, specifically, perturbation is any action that unbalances a stable rally (a rally where there is no obvious advantage to any of the players) thereby creating an advantage to the player that produced that action (i.e. perturbation). These authors analysed perturbations created from the baseline to investigate how the players' positioning in the court influences the interpersonal coordination tendencies (Carvalho, Araújo, Travassos, Esteves, et al., 2014; Carvalho, Araújo, Travassos, Fernandes, et al., 2013), following quantitative methods developed by Palut and Zanone (2005) and Lames (2006) to study coordination by capturing the relative motion (space:time) of tennis players. Despite these insights, little is known about the specific context that characterises the decoupling of the players, which is often associated with scoring points situations (Carvalho, Araújo, Travassos, Esteves, et al., 2014; Carvalho, Araújo, Travassos, Fernandes, et al., 2013; Palut & Zanone, 2005).

Notational analysis registers frequencies of actions in the sport context and has been used by O'Donoghue and Ingram (2001) and by Filipcic (2003) to study tennis based on performance-related indicators. O'Donoghue and Ingram (2001) focused on the study of the duration of the points depending on the court surface and the influence of the court surface on the serve. Filipcic (2003) characterized four Grand Slam finals and studied the influence of the serve and return upon the discussion of the match and he also compared some performance indicators between winners and losers.

In the current study, we address some limitations of this research method. Specifically, the analyses in these studies i) focus on accumulated frequencies of actions (i.e. their result), which are decoupled from the behavioural interactions of a game (Hughes & Bartlett, 2002); ii) do not take into account the contextual circumstances that allow those actions (Araújo & Davids, 2009), even though they consider spatial (position on the court) and chronologic (minutes of play) aspects of the match; iii) do not consider sequences of actions (as opposed to Gorospe, Mendo, Anguera & Santos, 2005, who used sequential analyses to study players interactions during a tennis game). This way of analysing human behaviour can be reductionist, once it is not able to describe the emergent interactions between players, in key areas of the pitch, that sustain and produce skilled performance (Vilar, Araújo, Davids & Button, 2012). In conclusion, notational analysis in tennis has been used in ways that are probabilistic, correlational and descriptive, resulting in data that lacks functional validity (Travassos, Davids, Araújo & Esteves, 2013). To describe and understand functional human behaviour it is fundamental to reference the ecological context where the goal directed actions are performed (Araújo, 2009; Travassos, Araújo, Correia & Esteves, 2010). Thus, there is currently a need for a theoretical rationale that incorporates the role of context on the analysis of frequencies and sequences of behaviours and therefore for the interpretation of the data collected (Hammond & Bateman, 2009).

In 2009, the International Journal of Sport Psychology paved the way for ecological approaches to sport psychology, by addressing the topic with a special issue publication entitled "Ecological approaches to cognition in sport and exercise". The main theoretical claim of ecological psychology is that, in order to understand behaviour, it is fundamental to study and describe the circumstances in which behaviour occur (Araújo, 2009). Specifically, the ecological environment is a highly important source of stimulus that can dictate the beginning and ending of actions, meaning that the human experience (psychological system) is significantly affected by events from the ecological system (Wicker, 2002). Ecological psychology´s approach try to guaranty that the physical and social constraints that act upon a person's behaviour are not ignored when studying action in sport (Araújo & Davids, 2009). This inter-connection and dependence between individual behaviour and the ecological environment is something that usually is not taken in consideration by the mainstream psychology (Araújo, 2009). In contrast, ecological psychology´s focus is not on the "inner processes" that underly performance, such as emotions and/or cognitions. Instead, it shifts its attention from the individual organism and its mental mechanisms to the study of the (functional) relations that are established between the individual and his ecological environment (Beek, 2009; Charles & Sommer, 2012; Hammond & Bateman, 2009; Wicker, 2002). Thus, ecological psychology "aspire to study and understand sports behaviour in terms of the actual environment and the broader context in which appears and evolves" (Beek, 2009, p. 144). So, it is its goal to describe and understand the ways that the performance environment constrains players' behaviours, while they are trying to achieve specific performance goals (Villar et al. 2012)

We aimed to identify the behaviours associated with perturbations from the baseline during a tennis match, and to characterize the context in which these behaviours occur, by using Barker's stream of behaviour and behaviour setting concepts (Araújo & Davids, 2009; Barker, 1963, 1968). In sports, Kaminski (2009) convincingly argued that Barker's methodological orientation stresses the importance of ecology in the analysis of behaviour. Barker (1968) assumes that the environment has a structure made of several parts, which have stable and interdependent associations between them. To illustrate the importance of the ecological context, Barker (1968) argues that there are fewer changes in certain behavioural attributes between different individuals in the same context, than within the same individual but in different contexts. Thus, an important part of the environment, termed "behaviour setting", should be seen as an extra-individual structure that, through certain processes, constrains behaviour to certain patterns, termed "streams of behaviour" (Barker, 1968). Moreover, this approach assumes that what attracts an individual to a given behaviour setting is his/her perception of opportunities to achieve his/her goals and available paths to attainment. These diversified paths are constrained by the ecosystem, the behaviour setting activities, and by the personal characteristics of the players. Behaviour settings have structural and dynamic properties (Barker, 1968; Heft, 2001). For instance, behaviour setting is a phenomenon that results from the interaction between individuals (it is not something constructed by a researcher) and which takes place within a certain "milieu". The milieu comprises the human-made environment (e.g. tennis court) and the natural environment (e.g. the sun, wind, etc.). Moreover, the behaviour setting has a detectable geographic location, and space and time boundaries that are self-generated by the individuals. Additionally, it is dynamically stable, and therefore retains a pattern of behaviours. Finally, the behaviour setting is independent of the players, but the behaviours that players display depend on the behaviour setting structure.

Importantly, behaviour settings not only constrain behaviour, but also promote its variability. As Barker (1968) proposes, "behaviour settings require conformity of their inhabitants, but they do not require uniformity" (p. 195). Thus, Barker's behaviour setting is a dynamic and interactive system, self-regulated and self-maintained. These structural and dynamic characteristics can be used for characterising a tennis match, and thereby to select data that explains the players' behaviour, such as contextually defined patterns of action. Notational analysis is a methodology that can provide this type of data (named "T-Data" by Barker) describing the context of streams of behaviour.

To capture psychological experiences within an environmental context, the ecological psychologist James Gibson (1979) created the concept of 'affordance'. Affordances are environmental properties with a functional significance for an active individual, i.e. they are the properties of a given environmental context that define the action possibilities of an individual. Thus, affordances are relational properties, referring simultaneously to the individual and their environment. Action facilitates the perception of the environmental properties, and perception is a process of detecting regularities in the environment. Heft (2013) argues that behaviour settings emerge from the mutually interdependent character of behaviours and affordances. Behaviour settings are dynamic eco-behavioural entities that operate at a higher level of complexity than the individual, and they comprise the collective actions of individuals and the physical milieu (affordances). By the very process of joining a collective pattern of action, individual's choices are generally constrained, falling within the range of actions considered appropriate to maintain the collective pattern. The actions may appear spontaneous when examined at the level of the individual (the stream of action), but when considered from the standpoint of the behaviour settings, the actions are indeed constrained and patterned.

Since individuals experience the environment relative to their body and skills, they are attuned to affordances. Affordances are meaningful within the dynamic person-environment system. Moreover, behaviour settings do not cause particular streams of behaviour among participants. Indeed, Barker (1968) argued that settings coerce rather than cause behaviour, which means that individuals conform to the operations of a behaviour setting by participating in them. Participation entails engaging in actions that are situationally normative, and normativity is conveyed and sustained through meanings that are carried within the overall dynamic structure of the behaviour settings.

The behaviour setting theory is, therefore, able to link chronological and spatial information with socio-cultural behaviour and has the capacity to "connect supra-individual conceptualizations with individual-based ones" (Kaminski, 2009, p. 60).

As Kaminski (2009) remind us that, when researching in ecological psychology, reality is so complex that it is not possible to capture it all at once. In that way, it is important to choose and define fundamental domains of categories in order to compose the fields of ecological exploration. Ecological psychology can focus on "people"; "activities"; "contextual conditions" and the "chronological aspects" that surround the activities, to then try to capture and describe, to the maximum extent, the completeness of the fields of ecological exploration previously defined. In the present study, we want to identify and characterize perturbations created from the baseline in tennis using an ecological psychology approach. To do it so, we defined two main fields of ecological exploration, one for the behaviour setting and one for the stream of behaviour. In each of those fields of ecological exploration, the fundamental domains of categories were: on the "people" domain, the player responsible for the perturbation and his opponent; on the "activities" domain, all the technical actions, areas of the court and movement patterns imposed by each player over his opponent; on the "contextual conditions", the full description of the tennis court and all its playable area, as well as a constant reference for both players actions; for the "chronological aspects" we employed a sequential analyses method that captured the context that surrounded the perturbations, by describing the moments before, during and after each perturbation. We used a behavioural mapping technique (Pinheiro, Elali & Fernandes, 2008; Sommer & Sommer, 2002) based on non-invasive observation (video analyses) to characterise the players' actions while describing the contextual conditions of each rally. Our goal was to describe the performance environment and the ways that players adapt to it, while they are interacting in perturbations created from the baseline, using the Roger Barker's "stream of behaviour" and "behaviour setting" theoretical concepts and methods. By doing it so, we wanted to describe the functional behaviour that players engage while pursuing their performance goals.

Materials and Methods

Sample

Four matches of the 2008 Estoril Open, an ATP World Tour 250 tournament played on a clay surface, were recorded, with a total of 530 points played and recorded. Eight professional players were involved in the four matches, with their world rankings as follow: two players in the top 5; two players in the top 100; two players in the top 200; one player in the top 400 and one player in the top 800. According to the criteria defined in previous studies (Carvalho, Araújo, Travassos, Esteves, et al., 2014; Carvalho, Araújo, Travassos, Fernandes, et al., 2013), two independent tennis experts selected (from the recorded 530 points) the rallies that ended due to a perturbation created from the baseline (n=80) (see procedures about this selection below). These experts were both experienced tennis coaches with more than 10 years of experience training elite players, with a sport sciences degree, and professional certifications recognized by the International Tennis Federation (ITF). The 80 rallies were characterised by 1) a balanced interaction between players (with no obvious advantage to any of the players) when they were both positioned behind the baseline; and 2) ending of the rally due to an action performed from the baseline that perturbed that state of balance (giving to one of the players a clear advantage).

Procedures for the rallies' selection. 530 rallies from four matches of the Estoril Open 2008 were recorded in video format. The filming was performed from the south top of the central court by using a Panasonic mini dv NV 621 E video camera. The camera was strategically positioned to capture the entire tennis court. A system of observational categories was developed to identify the points that ended due to a perturbation created from the baseline (PCB perturbation).

System of observational categories to detect the rallies that ended due to a PCB perturbation. The categories defined to describe the end of each point were as follows: 1) PCB perturbations (PCB): During a stable rally (with no obvious advantage to any of the players), who are both positioned behind the baseline, one of the players executes an action that perturbs the opponent and gives him a clear advantage that leads to the end of the point. Disturbance situations were identified based on the technical evaluation of the strokes and displacements, the position of the players on the court and the outcome of the action (according to the criteria reported in Carvalho, Araújo, Travassos, Esteves, et al., 2014; Carvalho, Araújo, Travassos, Fernandes, et al., 2013). It should be noted that the action promoting the perturbation had to be performed behind the baseline, but the rest of the rally could be played in any part of the court. 2) Other situations (OS): All the points that end for reasons other than a PCB perturbation. The observation and identification of PCB perturbations was performed by the two researchers mentioned above by using video editing software. Out of the 530 observed rallies, 80 (15%) were classified in the category PCB and the remaining 450 (84%) included in the category OS.

Validity. The design of this system of observational categories was presented to the two aforementioned tennis experts and another tennis expert, who is a former professional ATP player with professional certification recognized by ITF and over 10 years of experience coaching elite players. These experts agreed that the observational categories corresponded to the game situations described above. To validate this observation system, it was conducted an exploratory study by performing a systematic observation of 50 rallies. This study showed that the observational system functioned in practice, once the researchers had no problems with the interpretation and coding procedures of the observational categories system, meaning that the categories are exhaustive and adequate (Anguera, 1997, 1999).

Intra and inter observer fidelity. The percentage of agreement for intra-observer fidelity was 96,4% to one of the researchers and 100% to the other researcher. Inter-observer fidelity was 96,2%. These values guarantee the fidelity of this observation system (James, Taylor & Stanley, 2007).

Procedures for Coding the Stream of Behaviour at the Behaviour Setting

By using behaviour mapping techniques (Pinheiro et al., 2008), the selected rallies (n=80) were analysed in terms of: (i) the action zones occupied by the players during the rallies; (ii) the players' action modes (techniques) and the direction, effect and speed imposed on the ball; and (iii) the displacements performed by the players.

Action Zones. An action zones system was designed with the input of the three experts panel mentioned above. This system geometrically divided all the available play space in 80 zones of action, with 40 action zones in player's A (the author of the perturbation) court and 40 action zones in player's B (the player who responded to the perturbation) court (see Figure 1), with the aim of identifying specific areas associated with changes in the dynamics of the rally. The definition of the number and size of the action zones used in this system was the result of several debates between the experts, regarding the precision and relevance of the action zones.

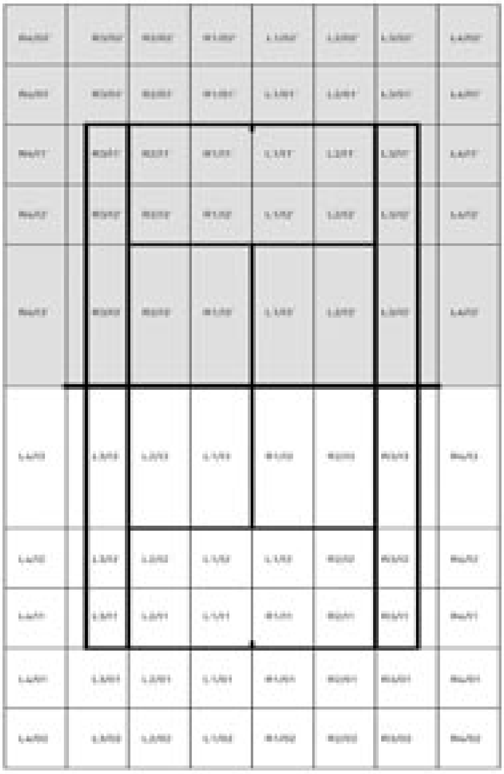

Fig. 1. - *Action zones system.* Diagram of a tennis court with the playable area geometrically divided in 80 zones of action, including 40 zones for each of the players. Each zone has a specific denomination as follows: R or L (right or left hand-side of the field from the player's perspective); I or O (inside or outside the baseline of the field). The right and left hand-side zones were divided in four parts (R1-4 and L1-4), the outside the baseline zones in two parts (O1-2) and the inside the base line zones in three parts (I1-3). To distinguish between player A and B's action zones, the denominations of player B's zones are marked with an inverted comma (') (e.g., L4/O2'). The field of player A is in white, whereas the field of player B is coloured in grey.

Additionally, we identified four distinct moments: Moment 1: when player A is executing the shot preceding the perturbation (his next shot); Moment 2: when player B is executing the shot that responds to moment 1; Moment 3: when player A responds to moment 2 and executes the shot causing the perturbation (which dictates the end of the point); and Moment 4: when player B executes the shot that responds to moment 3. Moments 1 to 3 were also used in other analyses, as we describe next.

Action Modes. To characterise the action modes (i.e., the technical gestures) performed by the players, we used an observational system with four observational macro-categories (Anguera, 1999): technical action, direction, effect and velocity of the ball (Table I). Using this system, we characterised every rally in a sequential mode over moments 1, 2 and 3, as explained before.

Table I
Technical Macro-Categories. Definition Of Four Technical Macro-Categories And Their Sub-Categories.

Macro-category	Category	Definition
Technical action	Forehand (**For**)	For a right-handed player, it is a stroke executed on the right side of the body. For a left-handed player, it is a stroke executed on the left side of the body.
	Backhand (**Bac**)	For a right-handed player, it is a stroke executed on the left side of the body. For a left-handed player, it is a stroke executed on the right side of the body.
	"Running around" the forehand (**-For**)	For a right-handed player, it is the execution of a forehand stroke on the left side of the court. For a left-handed player, it is the execution of a forehand stroke on the right side of the court.
	"Running around" the backhand (**Bac-**)	For a right-handed player, it is the execution of a backhand stroke on the right side of the court. For a left-handed, it is the execution of a backhand stroke on the left side of the court.
	Serve (**Ser**)	The technique used to start each point.
Direction	Down the line (**Dow**)	A ball played down one of the lateral lines of the court, being the opposite of a ball played in a diagonal trajectory that crosses from one side to the other side of the court.
	Cross court (**Cro**)	A ball played in a diagonal trajectory that crosses from one side to the other side of the court, being the opposite of a ball played down the line.
	In Side Out (**InOu**)	A ball played diagonally, from the centre to the side of the court, without crossing the central (vertical) line that divides the court
	Out Side In (**OuIn**)	A ball played diagonally, from the side to the centre of the court, without crossing the centre (vertical) line that divides the court.
Effect	Top Spin (**Top**)	When the ball is flying with a forward rotation spin applied by the player.
	Slice (**Slic**)	When the ball is flying with a backwards rotation spin applied by the player.
	Flat (**Flat**)	When the ball is flying with no obvious forward or backwards spin.
Velocity	Acceleration (**Ace**)	When a ball is played with an obvious acceleration, when compared with the velocity of the ball previously played by the opponent.
	Maintaining (**Man**)	When a ball is played with no obvious acceleration or deceleration, when compared with the velocity of the ball previously played by the opponent.
	Deceleration (**Des**)	When a ball is played with an obvious deceleration, when compared with the velocity of the ball previously played by the opponent.

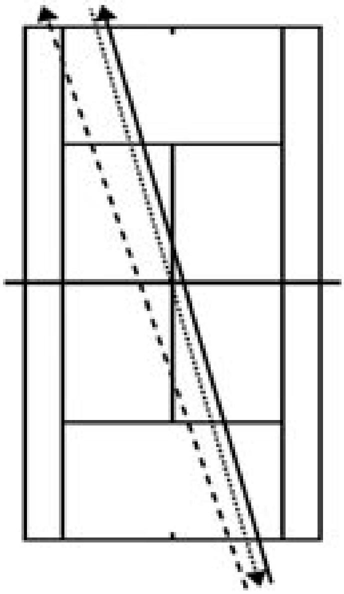

Fig. 2a

<table>
<tr><th>Action zone</th><th>Moment1 (player A)</th><th>Action Zone</th><th>Moment 2 (Player B)</th><th>Action Zone</th><th>Moment 3 (Player A)</th><th>Action Zone</th></tr>
<tr><td>R2/O2</td><td>For|Cro|Top|Man</td><td>R2/O1'</td><td>For|Cro|Top|Man</td><td>R2/O2</td><td>For|Cro|Top|Man</td><td>R3/O1'</td></tr>
</table>

Fig. 2b

Fig. 2. - *Illustration of a complete characterisation of a rally.* Figure 2a) shows the procedure used to characterise the displacements imposed by the players on the opponent. The ball trajectory is shown during the moments related to a perturbation, represented by different arrow types:

———➤ Player A's shot preceding the perturbation (his next shot);
---------➤ Player B's shot preceding the perturbation;
---------➤ Player A's shot causing the perturbation.

Figure 2b) shows a behavioural sequence with the combination of the action mode notations with the action zones (see also Figure 1 and Table 1).

The sequential notation of the technical actions performed by the players was combined with the position (action zone) that they occupied in each of those moments of analysis (see Figure 2).

Imposed displacement to the players. The displacements imposed by each player on his opponent were characterised sequentially over Moment 1, Moment 2 and Moment 3 (Figure 2).

In Figure 2a, different types of arrows are used to represent the ball trajectory and the position of players A and B on the court (action zones) during the three moments of analysis. The start of the arrow is located on the zone where player A or B hit the ball, and the end of the arrow is placed on the zone where the opponent hit the ball (on his response). The type of displacements imposed by each player on his opponent can be identified with this system. Figure 2b shows the same stream of behaviour: In moment 1, in the action zone R2/O2, player A executed a crosscourt forehand stroke, with top spin and maintaining ball velocity, which displaced player B to the action zone R2/O1', where player B executed a crosscourt forehand stroke, with top spin and maintaining ball velocity, which displaced player A to the action zone R2/O2. Finally, in this zone player A executed a crosscourt forehand stroke, with top spin and maintaining ball velocity, which displaced player B to the action zone R3/O1', creating a perturbation that determined the end of the point.

We characterised each play by combining the data in four different focus of analysis (Table II). These four focus of analysis were needed to obtain different layers of granularity and to detect patterns of behaviour at various detail levels. The first focus of analysis contemplates the sequence of all the technical categories of observation and action zones; the second focus of analysis contemplates the sequence of all the technical categories of observation without the action zones; the third focus of analysis contemplates the sequence of only the first two technical categories of observation without the action zones; the fourth focus of analysis contemplates only the sequence of the action zones.

Table II
Illustration Of The Four Focus Of Analyses Used To Characterise The Behavioural Sequences Of Each Rally. Player A – Player Who Performs the perturbation that causes the end of the point; Player B – The player that responds to the perturbation; Moment 1 – Player A's shot preceding the perturbation; Moment 2 – Player B's shot that responds to moment 1; Moment 3 – Player A's shot causing the perturbation (see also Figure 1 and Table 1).

Focus of analysis	**Action zone**	**Execution in moment 1 (player A)**	**Action zone**	**Execution in moment 2 (player B)**	**Action zone**	**Execution in moment 3 (player A)**	**Action zone**
1	R2/O2	For|Cro|Top|Man	R2/O1'	For|Cro|Top|Man	R2/O2	For|Cro|Top|Man	R3/O1'
2		For|Cro|Top|Man		For|Cro|Top|Man		For|Cro|Top|Man	
3		For|Cro		For|Cro		For|Cro	
4	R2/O2		R2/O1'		R2/O2		R3/O1'

Results

Our results showing how players A (the author of the perturbation) and B (the player that suffers the perturbation) each occupied 40 zones of action reveal how they utilised the space of the behaviour setting. Moreover, we describe the modes of action chosen by each player over three sequential shots during the rallies (stream of behaviour). Finally, our analyses describe the displacements made by the players in response to the perturbations, thereby uncovering the patterns of behaviour caused by perturbations.

Action Zone Utilisation

The action zones that were occupied more often (i.e. two or more times) during the four moments of analysis are presented in Table III. We show the results for each single match and also for the ensemble of the four matches.

In the results of Table III it is important to highlight which action zones were preferably used by players A and B in moments 1, 2, 3 and 4. The number of occurrences (occupation of the zones) was used to establish the players' preferred action zones. Looking at the results regarding the total of

Table III
Action Zone Utilisation During The Four Moments Of Analysis. The Number Of Occurrences Is In Bold (See Also Figure 1 For notations).

	Action zones and number of occurrences in moment 1		Action zones and number of occurrences in moment 2		Action zones and number of occurrences in moment 3		Action zones and number of occurrences in moment 4	
	Player A	Player B	Player A	Player B	Player A	Player B	Player A	Player B
Match 1	L2/O1 **6** R2/O1 **6**	L1/O1´ **5** R1/I1´ **5**	L1/O1 **8** R1/O1 **7**	L1/O1´ **7** R1/O1´ **6**	L1/O1 **7** R1/O1 **7**	R1/O1´ **9** L1/O1´ **9**	R1/O1 **8** L1/O1 **7**	R2/O1´ **7** L1/O1´ **5**
Match 2	L2/O2 **5** L2/O1 **4**	L2/O1´ **6** L1/O1´ **4**	L2/O1 **6** L1/O1 **5**	L2/O1´ **8** L3/O1´ **4**	L2/O1 **8** R1/O1 **4**	L2/O1´ **11** L1/O1´ **3**	L2/O1 **8** R1/O1 **6**	L3/O1´ **5** L2/O1´ **3**
Match 3	L1/O1 **6** L2/O1 **5**	R1/O1´ **5** L2/O1´ **4**	L1/O1 **8** L2/O1 **6**	L2/O1´ **7** L1/O1´ **5**	R1/O1 **6** L2/O1 **5**	L1/O1´ **10** L2/O1´ **6**	L2/O1 **8** L1/O1 **7**	R2/O1´ **6** L3/O1´ **4**
Match 4	R2/O1 **5** L2/O1 **3**	R1/I1´ **3** L1/I1´ **3**	L1/O1 **3** R1/O1 **3**	L1/O1´ **5** L1/I1´ **3**	L2/O1 **3** L1/O1 **3**	L1/O1´ **9**	R1/O1 **7** L1/O1 **4**	R1/O1´ **3** R2/I2´ **2**
Total of matches	L2/O1 **18** L1/O1 **13** R2/O1 **13**	L2/O1´ **14** L1/O1´ **13** R1/O1´ **13**	L1/O1 **24** R1/O1 **16**	L2/O1´ **22** L1/O1´ **18**	R1/O1 **20** L2/O1 **18**	L1/O1´ **31** L2/O1´ **18**	R1/O1 **25** L1/O1 **20**	R2/O1´ **15** L3/O1´ **12**

matches we can see that, in moments 1,2,3 and 4, players A and B prefer the use of certain action zones. For example, in moment 1, player A's preferred action zone is L2/O1 followed by the action zones L1/O1 and R2/O1 (both with 13 occurrences), while player B's preferred action zone is L2/O1' followed by the action zones L1/O1' and R1O1' (both with 13 occurrences). In moment 2, player A would rather use the action zone L1/O1 followed by R1/O1, while player B use´s more often the action zone L2/O1' followed by L1/O1'. The same happens in moments of analysis 3 and 4, with player A and B having an order of preference regarding the use of specific action zones. If we compare the action zones that player´s A and B preferred to use in moments 1,2,3 and 4 in the total of matches with the action zones that player's A and B preferred to use in the same moments of analyse in each match, we can see that they do not always coincide. As an example, while in moment 2 for the total of matches player A used more often the action zone L1/O1 followed by R1/O1 (as in match 1 and 4), in match 2 player A preferred to use the action zone L2/O1 followed by L1/O1 and in Match 3 player A preferred to use the action zone L1/O1 followed by L2/O1. In the same moment 2 of analysis and for the total of matches player B used more often action zone L2/O1' followed by L1/O1' (as in match 3), while in match 1 player B preferred the use of action zone L1/O1' followed by R1/O1', in match 2 player B preferred the use of action zone L2/O1' followed by L3/O1' and in match 4 player B preferred the use of action zone L1/O1' followed by L1/I1'. The same observation can be extended to moments of analysis 1, 3 and 4.

Descriptive results presented in Table III show that the action zones most used by players are subject to variability across matches.

Action Mode Utilisation

We performed four focus of analysis on the sequences of technical gestures used by players A and B in each rally, in order to verify the existence of repetitions of specific sequences of action. These results are presented for each single match and for the total of matches in Table IV. The results of Match 4 are not presented because there were no repetitions of behavioural sequences in any of the focus of analysis. Table IV shows only repeated behavioural streams.

Interestingly, regardless of the focus of analysis, few sequences of technical behaviours or action zones utilised were repeated by either of the players in response to perturbations from the baseline (PCB perturbations).

Table IV

Characterisation Of The Behavioural Sequences Of Match 1 (Table 4a), Match 2 (Table 4b), Match 3 (Table 4c), And The Total Of Matches (Table 4d), Using Four Focus Of Analysis (See Figure 1, Table 1 And Table 2 For notations).

Table 4a — **Match 1**

<table>
<tr><th>Focus of analysis</th><th>Action zone</th><th>Execution in moment 1 (player A)</th><th>Action zone</th><th>Execution in moment 2 (player B)</th><th>Action zone</th><th>Execution in moment 3 (player A)</th><th>Action zone</th><th>Number of repetitions</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>3</td><td></td><td>For|Cro</td><td></td><td>For|Cro</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|Dow</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td>4</td><td>R2/O1</td><td></td><td>R1/O1’</td><td></td><td>L1/O1</td><td></td><td>L3/O1’</td><td>1</td></tr>
</table>

Table 4b — **Match 2**

<table>
<tr><th>Focus of analysis</th><th>Action zone</th><th>Execution in moment 1 (player A)</th><th>Action zone</th><th>Execution in moment 2 (player B)</th><th>Action zone</th><th>Execution in moment 3 (player A)</th><th>Action zone</th><th>Number of repetitions</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>2</td><td></td><td>Ser|Cro|Top|Ace</td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>Bac|Dow|Top|Man</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|Cro</td><td></td><td>Bac|Cro</td><td></td><td>4</td></tr>
<tr><td>3</td><td></td><td>Bac|Cro</td><td></td><td>-For|OuIn</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|OuIn</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Ser|Cro</td><td></td><td>Bac|Cro</td><td></td><td>Bac|Dow</td><td></td><td>1</td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
</table>

Table 4c — **Match 3**

<table>
<tr><th>Focus of analysis</th><th>Action zone</th><th>Execution in moment 1 (player A)</th><th>Action zone</th><th>Execution in moment 2 (player B)</th><th>Action zone</th><th>Execution in moment 3 (player A)</th><th>Action zone</th><th>Number of repetitions</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>3</td><td></td><td>Bac|Cro</td><td></td><td>-For|OuIn</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
</table>

Table 4d — **Total of matches**

<table>
<tr><th>Focus of analysis</th><th>Action zone</th><th>Execution in moment 1 (player A)</th><th>Action zone</th><th>Execution in moment 2 (player B)</th><th>Action zone</th><th>Execution in moment 3 (player A)</th><th>Action zone</th><th>Number of repetitions</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td></td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>-For|Cro|Top|Man</td><td></td><td>1</td></tr>
<tr><td>2</td><td></td><td>Ser|Cro|Top|Ace</td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>-For|OuIn|Top|Ace</td><td></td><td>For|Cro|Top|Des</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>Bac|Cro|Top|Man</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|Cro</td><td></td><td>Bac|Cro</td><td></td><td>5</td></tr>
<tr><td></td><td></td><td>For|Cro</td><td></td><td>For|Cro</td><td></td><td>For|Cro</td><td></td><td>3</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|OuIn</td><td></td><td>For|Cro</td><td></td><td>3</td></tr>
<tr><td></td><td></td><td>For|Cro</td><td></td><td>For|Cro</td><td></td><td>For|InOu</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac-|Dow</td><td></td><td>Bac|Cro</td><td></td><td>Bac|InOu</td><td></td><td>1</td></tr>
<tr><td>3</td><td></td><td>Bac|Cro</td><td></td><td>Bac|Dow</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|Cro</td><td></td><td>-For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Bac|Cro</td><td></td><td>Bac|Cro</td><td></td><td>-For|Down</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>-For|Cro</td><td></td><td>Bac|OuIn</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>-For|Dow</td><td></td><td>For|Cro</td><td></td><td>For|Cro</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Ser|Cro</td><td></td><td>Bac|Dow</td><td></td><td>Bac|Dow</td><td></td><td>1</td></tr>
<tr><td></td><td></td><td>Ser|Cro</td><td></td><td>Bac|Cro</td><td></td><td>Bac|Dow</td><td></td><td>1</td></tr>
<tr><td></td><td>R2/O1</td><td></td><td>R1/O1’</td><td></td><td>L1/O1</td><td></td><td>L3/O1’</td><td>1</td></tr>
<tr><td>4</td><td>R2/O1</td><td></td><td>L1/O1’</td><td></td><td>R2/O1</td><td></td><td>L2/O1’</td><td>1</td></tr>
<tr><td></td><td>L1/O1</td><td></td><td>L2/O1’</td><td></td><td>R1/O1</td><td></td><td>R2/O1’</td><td>1</td></tr>
</table>

Moreover, patterns of behavioural sequences in one match are not replicated in other matches, suggesting that behavioural sequences are specific to each individual. Thus, there is high variability of behavioural sequences across matches for players A and B, regarding their action modes and the occupation of action zones.

Displacements Imposed By The Players During The Perturbations

Our results revealed seven categories of displacements used by player A to create PCB perturbations upon player B: 1) Diagonal – Open space; 2) Diagonal – Counter movement; 3) Parallel – Open space; 4) Parallel – Counter movement; 5) Depth displacement; 6) Ball acceleration; and 7) Ball depth. The displacement categories are illustrated in Figures 3 and 4. Every type of displacement can be performed on both sides of the court and shows highly variable amplitudes of displacements.

Figures 3a and 3b show the "Diagonal – Open space" category resulting from a diagonal interaction between the players on one side of the court, thereby allowing the exploration of an "open space" on the opposite side of the court.

Figures 3c and 3d represents the "Diagonal – Counter movement" category, consisting of a diagonal interaction between the players on one side of the court. Because the players need to return towards the middle of the court after each shot, this type of displacement allows the exploration of a "counter movement space" on the same side of the court.

Figures 3e and 3f shows the "Parallel – Open space" category resulting from a parallel interaction between the players on the same side of the court, thereby allowing the exploration of an "open space" on the opposite side of the court.

Figure 3g and 3h shows the "Parallel – Counter movement" category, which results from a parallel interaction between the players on the same side of the court. Because the players need to return towards the middle of the court after each shot, this type of displacement allows the exploration of a "counter movement space" on the same side of the court.

Finally, in some rallies the shot causing the perturbation (last shot of player A) does not lead to a significant lateral displacement of player B. However, the perturbation may impose a significant "depth displacement" of player B (forward or backwards), or significantly increase the speed of the ball ("ball acceleration") or changes on the depth of its trajectory ("ball depth"). Figure 4 illustrates these types of displacements, which can be per-

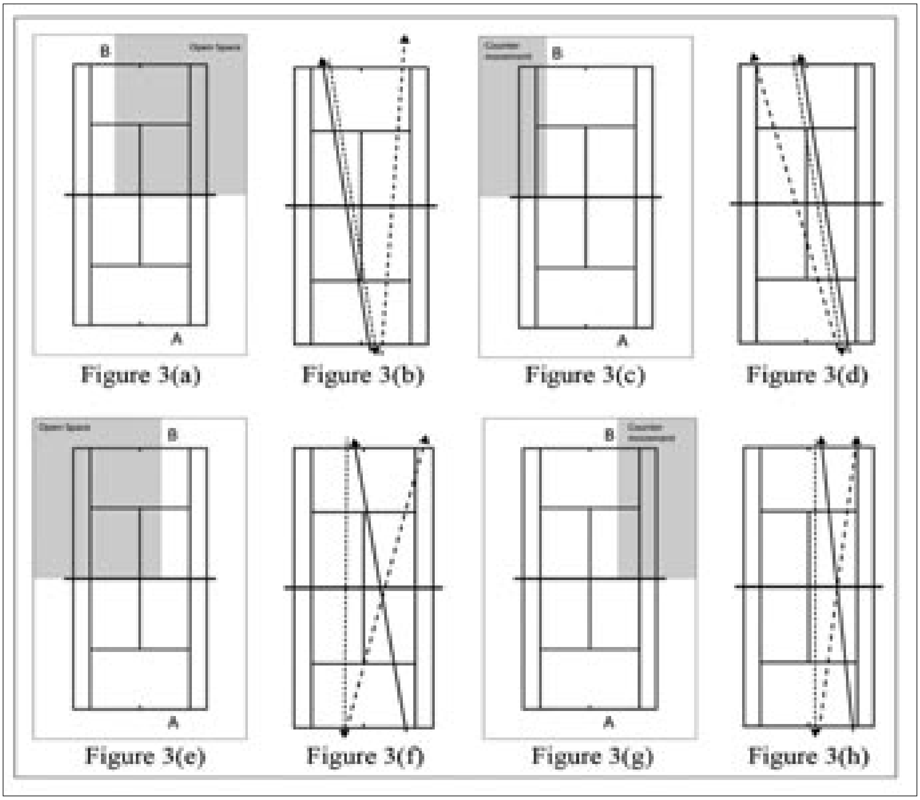

Fig.3. - Diagram showing the displacement categories “Diagonal – Open space”, “Diagonal – Counter movement”, “Parallel – Open space” and “Parallel – Counter movement”. Figure 3a is an example of a created open space from a diagonal pattern of interaction and Figure 3b illustrates one of the rallies from this category; Figure 3c is an example of a created counter movement space from a diagonal pattern of interaction and Figure 3d illustrates one of the rallies from this category; Figure 3e is an example of a created open space from a parallel pattern of interaction and Figure 3f illustrates one of the rallies from this category; Figure 3g is an example of a created counter movement space from a parallel pattern of interaction and Figure 3h illustrates one of the rallies from this category. The arrows reveal the moments analysed (Moments 1-3):

———➤ Player A’s shot preceding the perturbation (his next shot);
----------➤ Player B’s shot preceding the perturbation;
---------➤ Player A’s shot causing the perturbation.

formed on both sides of the court and with highly variable amplitudes of displacements.

In Table V are described the categories of displacements that were

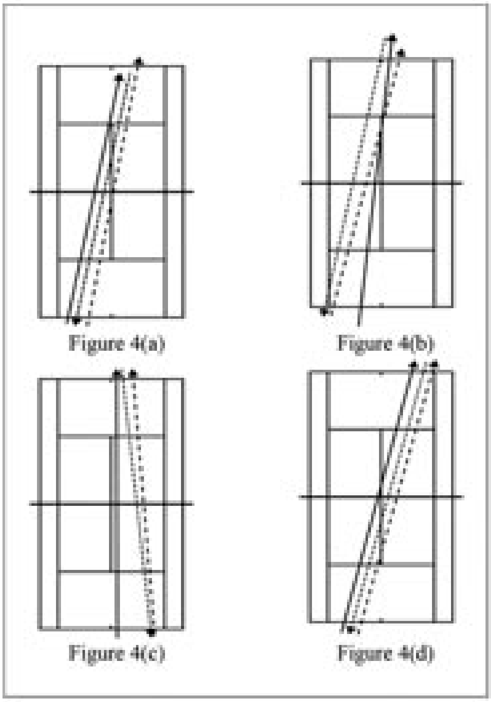

Fig. 4. - Examples of rallies from the displacement categories "Depth displacement", "Ball acceleration" and "Ball depth". Figure 4a and 4b illustrates the "Depth displacement" category; Figure 4c illustrates the "Ball acceleration" category; and Figure 4d illustrates the "Ball depth" category (see Figure 3 for arrows' notation).

preferably utilized by players A and B in each of the four matches as well as in the total of matches.

The results of these analyses (Table V) indicate that, from the 80 plays that were selected from the initial sample of 530 plays, 80% (n=64) of the PCB perturbations were achieved by imposition of the displacements categories: "Diagonal – Open space", "Diagonal – Counter movement", and "Parallel – Open space". We have performed a qui-squared test on the data presented in Table 5 and the results show that the frequencies of the displacement categories "Diagonal – open space", "Diagonal – counter movement" and Parallel – Open space" are above the expected frequencies. Moreover, the difference between the observed

Table V

Absolute And Relative Frequencies Of The Displacement Categories Imposed By Players A And B During The Perturbations, For Every Match And Total of matches.

Displacement categories	Match 1	Match 2	Match 3	Match 4	Total of matches
Diagonal – Open space	N=4 **(18,18%)**	N=6 **(27,27%)**	N= 8 **(36,36%)**	N=6 **(42,86%)**	N=24 **(30%)**
Diagonal – Counter movement	N=3 **(13,67%)**	N=6 **(27,27%)**	N= 7 **(31,81%)**	N=2 **(14,29%)**	N=18 **(22,50%)**
Parallel – Open space	N=8 **(36,36%)**	N=7 **(31,81%)**	N=5 **(22,73%)**	N=2 **(14,29%)**	N=22 **(27,50%)**
Parallel – Counter movement	N=2 **(9,09%)**	N=1 **(4,50%)**	N=1 **(4,50%)**	N=0 **(0,00%)**	N=4 **(5%)**
Depth Displacement	N=1 **(4,50%)**	N= 1 **(4,50%)**	N= 0 **(0,00%)**	N=1 **(7,14%)**	N=3 **(3,75%)**
Ball Acceleration	N=3 **(13,67%)**	N= 0 **(0,00%)**	N= 0 **(0,00%)**	N=2 **(14,29%)**	N=5 **(6,25%)**
Ball Depth	N=1 **(4,50%)**	N=1 **(4,50%)**	N=1 **(4,50%)**	N=1 **(7,14%)**	N=4 **(5%)**

frequencies of all the displacement categories is highly significant, $\chi 2(6)_{=} 48{,}82$, ($p<0.001$).

Discussion

The goal of this research was to identify and characterize perturbations created from the baseline in tennis (PCB perturbations) and to describe the ways that they constrain the functional adaptations of tennis players, while they are pursuing this specific performance goal. For that purpose, we used an ecological psychology approach and tested Barker's (1963, 1968) behaviour setting theory. We defined two fields of ecological exploration, the behaviour setting and the stream of behaviour, and we used methods that were able to collect "T-Data" information to describe and characterize 80 PCB perturbations.

Perturbations Create Highly Constrained Affordances For The Opponent

The analysis of the action zones utilised by the players (Table 3) shows that players A (the author of the perturbation) and B (the player that suffers the perturbation) prefer the use of certain action zones depending on the moment of analysis (1,2,3 or 4), as shown in the results for the total of matches. As an example: in moment 1, player A prefers action zone L2/O1 followed by the action zones L1/O1 and R2/O1 (both with 13 occurrences) and player B prefers action zone L2/O1' followed by the action zones L1/O1' and R1O1' (both with 13 occurrences). However, the action zones that player A and B prefer to use in moments 1,2,3, and 4 in the total of all matches don´t always coincide with the ones that player A and B prefer to use in the same moments of analysis in each individual match (see Table III). The results show that the action zones most frequently used by players vary across matches. Taking in consideration the behaviour setting theory, it is only logical to consider that each shot, each rally and each match represents a unique context, that it is not repeatable in any other shot, rally or match. This contextual variability is due to: i) personal resources: e.g. the fatigue levels that are not the same during a match and affect the playing capacities; the emotional and cognitive processes that vary across a match and are dependent, for example, on the result and/or recent performances and also on the round or the importance of the tournament (e.g. it is not the same to play a final or a second round, as it is not the same to play a Grand Slam or a ATP 250); ii) contextual conditions: every ball that is played by the opponent is different in terms of speed, effect, placement or in the sequence of shots played before; the environmental conditions (the milieu) are always changing (e.g. wind sun, crowd, etc.); each opponent represents a different style of playing and therefore needs a different tactical and technical approach. This suggests that each match has its own signature, and that each player uses different areas of the tennis court from rally to rally in order to functionally adapt his available resources to a constantly changing context. These results are consistent with previous studies (Barker, 1968; Heft, 2001, 2013) suggesting that the same behaviour setting can be used in many different ways.

Results showed that streams of behaviour and sequential action modes were variable (Table IV). Indeed, the players use different combinations of actions to create PCB perturbations, indicating that similar functional relations are achieved by different behavioural means (Reed, 1982; Withagen & Michaels, 2005). This "rally to rally" variability in the action zones utilised and the articulation of technical actions during a PCB perturbation is consistent with some important theoretical aspects. First, the actions adopted in each behaviour setting are interconnected and dependent on the milieu (Barker, 1968), when the latter is described in terms of affordances (Gibson, 1979; Heft, 2013). As stated before, the personal and contextual conditions are different in every shot, rally or match, creating unique environmental properties that can generate specific possibilities for action. The rally to rally variability detected by the results of this investigation, concerning the technical actions and action zones used by each player, points to the fact that each rally offers different affordances, representing, therefore, different possibilities for action to each player. Second, this individuality and variability of behaviours performed in each rally shows that: i) the contextual and personal conditions that surround each perturbation are dynamic and represents different sets of affordances; ii) as a response to these dynamic properties of each rally, the same performance goal can be achieved in different functional ways. Although the players are pursuing mutually exclusive goals, they adopt the actions that better suit their individual characteristics and circumstances (Barker, 1968).

Our analysis of the displacements imposed by the players with an advantage on their opponent (Table V) shows that each player uses a limited number of behavioural patterns to create PCB perturbations for the opponent. We identified three categories of displacements that are used preferentially: "Diagonal – Open space", "Diagonal – Counter movement" and "Parallel – Open space". The other categories seem to present some limitations for the players. For example, the category "Parallel – Counter movement" is highly dependent on the exploration of the counter movement of the opponent, which supposedly represents a higher risk of execution for the player that creates the perturbation. Specifically, the player creating the perturbation has to aim his shot to the opposite direction in which the opponent is moving towards and without allowing him time to reverse his direction and receive the shot adequately, i.e., in a way that could give the opposing player the chance to cancel the perturbation or to create a counter perturbation. More than simply acting on affordances, players try to create affordances for the opponent (see Fajen, Riley & Turvey, 2009, for a review in sport) that will give them an advantage. Thus, perturbations can be seen as highly constrained affordances offered to the adversary to potentiate the possibility of own goal achievement. Specifically, the results of our investigation seem to indicate that, by means of highly variable behaviour (functional adaptations) concerning the choice of technical actions and zones of the court, PCB perturbations are achieved by the imposition of a set of patterns of displacement that constrain opposition behaviour and create specific affordances that limits the adversary possibilities for action.

In summary, our research has defined two fields of ecological exploration to describe PCB perturbations and the functional adaptations that tennis players exhibited during these game situations: the behaviour setting and the stream of behaviour. The results have detected: i) a significant variability, from match to match and from rally to rally, concerning the technical actions and zones of the court used by the players while they try to achieve a PCB perturbation. These results agree with Barker's hypothesis that the behaviour setting (e.g. rules of the game, dimensions of the court, height of the net, etc.) constrains the players' behaviour but does not prescribe it (Barker, 1968). Also, this behavioural variability might be an important way to functionally adapt to the dynamic properties of the behaviour setting, while players are pursuing their performance goals. On the other hand, players explore the behaviour setting, with actions that better suit their characteristics and momentary personal resources, to create affordances for the other player; ii) players preferably used a limited number of displacement patterns over their opponents in order to create PCB perturbations. These results also seem to corroborate another of Barker´s hypotheses, that the program of the behaviour setting (rules of the game, dimensions of the court, etc.) constrains the behaviour to certain patterns of action. This means that there is behavioural regularity (constrained by the behaviour setting) concerning the displacement patterns that players preferably use to create PCB perturbations. Also, the behaviours that players display, regarding their technical actions and occupation of the zones of the court, are highly variable and sensitive to the personal and contextual conditions.

Practical Applications

Our results may have implications to sports practice design. To stimulate and practice PCB perturbations, coaches can promote behaviour settings representative of a tennis match, by offering the players opportunities to adjust to the characteristics, shapes and movement patterns, as the rally evolves (Carvalho, Correia & Araújo, 2013; Hammond & Bateman, 2009; Smith, 2009). Thus, in this specific example, practice sessions could be designed in a way that promote the displacement categories identified in this study that emerge in situations of PCB perturbations. Moreover, results show a high variability in the technical actions and action zones used by each player, meaning that practice activities should allow players a chance to discover the most efficient way to respond to these displacement categories, depending on individual and contextual circumstances and possibilities to act.

Limitations and Future Lines of Research

It is our assessment that the limited sample size used in this investigation (80 rallies) it is not representative of a generic tennis match. Therefore, this research should be conducted with a bigger sample size, allowing for those types of generalizations.

The methods we used in this study may be further developed to analyse and profile the performance styles of players, including the opponents, which could be extremely helpful for match preparation. Finally, future research should address other remaining questions. For instance, how PCB perturbations change in different court surfaces, or how these perturbations can be cancelled.

Conclusion

Our results suggest that perturbations created from the baseline in tennis can be seen as highly constrained affordances for the opponent, which is consistent with the behavioural setting and stream of behaviour theoretical concepts proposed by Barker (Barker, 1968; Heft, 2001, 2013; see also Araújo & Davids 2009 for a discussion in sport). We show that tennis players use several unique combinations of action modes and use different action zones to create perturbations from the baseline and thereby impose certain patterns of displacement on their opponents.

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