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Interpersonal Dynamics in Baseline Rallies in Tennis

João Carvalho[1,2], Duarte Araújo[2,3], Bruno Travassos[4], Orlando Fernandes[5], Fernando Pereira[2,3] and Keith Davids[6]
[1]School of Education and Communication, University of Algarve, Campus da Penha, Estrada da Penha, 8005-139, Faro, Portugal
E-mail: joaohcarvalho@gmail.com
[2]CIPER, Interdisciplinary Centre for the Study of Human Performance, Portugal
[3]Faculdade de Motricidade Humana, Universidade de Lisboa, Portugal
[4]CIDESD, Department of Sport Sciences, University of Beira Interior, Portugal
[5]Department of Sports and Health, University of Évora, Portugal
[6]Centre for Sports Engineering Research, Sheffield Hallam University, UK

ABSTRACT
In tennis, the relative positioning of players on court constrains their opportunities to perform successful actions. In this study we proposed and validated an empirical function that captures the spatial-temporal relationship between tennis players during competitive performance. This parameter, termed *goal-directed displacement index* (GDD Index), is defined over time by the product of both players' distances to the central line of the court and to the centre of the net. Results showed that the GDD index successfully described tennis players' patterns of interaction, as well as identified breaks in patterns of play during competitive performance, due to changes in relative positioning on court. Our analysis revealed two different patterns of interpersonal interactions, *cross* and *down-the-line rallies*, and two ways for a break to emerge in game dynamics, *parallel variation* (transition from a cross court rally to a down-the-line rally) and *angle opening* (lateral displacement). Data suggest that the elaboration of specific individual profiles of performance for different players, using the GDD index, could improve performance analysis in tennis.

Key words: Game Dynamics, Performance Analysis, Tennis

INTRODUCTION

Performance analysis in tennis, using the notational approach, has focused on characterizing the most widely used and most effective actions or the most prevalent errors during

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competitive performance [1, 2]. These data define profiles of players' actions during competitive performance, but do not provide a theoretical rationale for understanding why different actions might emerge at any instant during competitive performance. A performance analysis methodology that can explain why specific actions emerge from different athletes could enhance the efficacy of sport science support in racquet sports.

In tennis, as in other racquet sports, some attempts have been made to understand the dynamical interactions between players during performance [3-6]. Results have shown how, through oscillating movements of players, the interdependence of actions in space and time is expressed during rallies [7]. To exemplify, in a cross-court backhand rally, the player about to hit the ball moves towards the left-hand side of his/her court, and the opponent moves towards the centre to defend his/her court[1] position and await the return. These coupling tendencies between competitors have been viewed as an emergent self-organised process under the ecological constraints of performance, since the players' goals are mutually exclusive, and they become linked by the information that is available to regulate their behaviours in the competitive environment [7-9].

In two opposing players, the coordination tendencies that emerge assume periods of stability and instability. From a natural law approach [e.g., 10], instability is often associated with perturbations in the player-environment system, which can shift the system towards a new state of organisation. If the balance between players' positions on court is not maintained over time (i.e., players' spatial-temporal symmetry), it may result in a symmetry breaking process and the conclusion of the point in racquet sports [7]. Some analyses of phase transitions in tennis have measured how a pattern of coordination emerges between the players in relation to a spatial reference point on court (e.g., the central mark on the baseline) [3, 6].This relationship between players and key spatial reference points on court represents their ability to manage the space of the playing area. The level of coupling between the two players has been captured through measuring their relative phase [11], an informational variable that can quantify the spatial-temporal relations of the lateral and/or longitudinal displacement on court between two competing players. For instance, using a single coordinate system, Palut and Zanone [3] revealed the existence of only two stable modes of synchronization (interaction), corresponding to players moving in the same direction (in-phase) or in opposite directions (anti-phase) during rallies in competitive tennis. During rallies, these stable coordination tendencies (system order) may be interrupted by periods of instability, in which system symmetry is lost (system disorder), and from which new states of stability or order arise (transitions) or the point is won by one player (rally breaks).

The observations reported by Palut and Zanone [3] have provided a better understanding of the relations established between tennis players during competitive performance. However, McGarry [12] has argued that for a functional understanding of competitive performance, the variables measured should combine information about the location on court where actions have emerged, as well as the nature of actions themselves. For instance, in the study of Palut and Zanone [3] the calculation of the relative phase variable took into account the oscillatory movement of participant lateral displacements in relation to the court centre. This methodology renders the analysis blind towards the spatial location of the players on the court, identifying differentiated functional relations (down-the-line or cross-court rallies) by the same mode of synchronization. To exemplify, with reference to two coordinate systems [6, 13], players can be moving in opposite directions directly facing each other on

[1]In the rest of this article, the term 'court' will be used to refer to the player's own half-court area. Reference to the whole court will be made with the term 'full court'.

the full court (i.e., playing on opposite sides of respective court) or interacting in a cross-court pattern (i.e., both on their left or right court side). That approach renders the tactical interpretation of the players' actions in relation to their position on the court difficult and makes it hard to understand the pattern forming dynamics which emerge during rallies.

Another limitation of the studies by Palut and Zanone [3] and Lames [6] is that they overlooked analysis of the movements of players towards or away from the net (longitudinal displacement trajectories). Although in a baseline rally the players' lateral movements (parallel to the baseline) may reach higher values in terms of magnitude of variation, the longitudinal movements of entering and exiting the court (perpendicular to the baseline) are crucial to the game and cannot be underestimated for understanding pattern forming dynamics of competitive performance. It is contended that, in order to understand the dynamics of competitive performance, research is needed that considers how the relative positioning of the players varies in relation to the central line of the court (lateral displacement) and the centre of the net (longitudinal displacement).

The objective of this study was to theoretically and empirically validate a spatial-temporal variable that captures and quantifies moments of stability, instabilities and breaks in patterns of play in competitive tennis. Advancing previous research on tennis, data on lateral and longitudinal displacements of competing players on a tennis court were combined in a single measure to describe the interpersonal coordination tendencies established during rallies at the moment when a ball is hit by each player. Two variables have been implicated in dyadic system transitions by the experiential knowledge of expert tennis coaches [14]: i) opening angle (i.e., one of the players displaces the other laterally based on the position relative to the centre of the net); and ii), parallel variation (i.e., the players are playing in a cross-court pattern and one of them hits the ball parallel to the sideline). Through analysis of these variables, we aimed to test the proposed spatial-temporal measure to identify performance situations when a transition might emerge in competing dyadic systems in tennis that lead to the winning of a point (i.e., a break in the coordination tendencies of the dyad). Our intention was to measure the spatial-temporal conditions that constrain the players' behaviours during competitive performance. This information could help coaches to design more appropriate training tasks and shape players' performance.

METHOD

To achieve our objective, we randomly selected for analysis three matches on the central court of the 2008 ATP Tour 250 in the Estoril Open in Portugal, a tournament played on clay. The process of data collection and treatment was carried out according to the ethical procedures of the University of Lisbon (Faculty of Human Kinetics), in accordance with the proposals of the American Psychological Association.

The movement displacements of the players and the ball during the three matches were captured with a digital video camera (Panasonic mini DV - NVG21E), placed at one end of the tennis court to cover the whole playing area. From the matches, 28 rallies were selected for further analysis according to criteria based on visual inspection (match1=8; match 2=9; match 3=11; see Data Analysis section below). The selected rallies were digitized using the TACTO 7.0 software [15, 16] in order to obtain the virtual coordinates (x, y) of the positions of the players on court over time. The procedure consisted of following frame-by-frame with a computer mouse the projection on the floor of the midpoint of the two feet of each player, during the course of each rally. In each rally, we also recorded the moment when the ball was struck or when it bounced on the court surface. The virtual coordinates (in pixels) of the position of the players on court during each rally were converted into real coordinates using the direct method of linear transformation (2D-DLT) [17], and the data were smoothed with the aid of a 6 Hz filter (a low pass filter), using the Matlab R2008a software [15].

DATA ANALYSIS

The 28 rally sequences were chosen according to two basic criteria: i) the ball had to be played from behind the baseline; and ii), there had to be at least one phase transition in the dyadic system coordination tendencies that existed between the players. Concerning the first criterion, after a service had been returned, there should be at least one stroke in which the two players were positioned behind the baseline, close to the central zone (neutral zone), with the return stroke made in a controlled way. Two expert tennis coaches performed this selection procedure with a percentage agreement of 98% and 100% intra-observer and of 96.2% inter-observer [18]. Concerning the identification of dyadic system transitions in the rallies, the strokes deemed responsible for the de-stabilising effect on coordination tendencies were identified by two expert tennis coaches. These expert judgements were made according to a set of criteria related to the way in which the strokes and the movement displacements were made (including balance in the stroke, the position of the contact zone of the racquet with the ball in relation to the body, the position of the players on the court, the impact of the ball resulting from that stroke in the displacement and in the stroke made by the other player; see Table 1).

Table 1. Criteria used to identify the strokes that originated breaks in the rallies

Events	Aspects observed	Balance	Unbalance
Stroke	• Shoulders position.	• Parallel to the end line.	• Non-parallel to the end line.
	• Head position.	• Vertical.	• Non-vertical.
	• Relative position of the geometrical centre to the support base.	• Geometrical centre inside of the support base.	• Geometrical centre outside of the support base; in displacement
	• Position of the point of impact of the racquet with the ball.	• Between shoulders and waist; Semi-flexion of the arm.	• Above shoulders or below the knee; Arm extension.
Position of the players on the court	• Relative position of the players.	• Both players positioned in a central zone of the court; ± at the same distance of the lateral line and the net.	• One of the players positioned closer to the net or the centre of the court than the other.
	• Players' position at the instant of the strike.	• Player who hits the ball was further from the central line or the baseline than the other.	• Player who hits the ball was closer to central line or the baseline than the other.
Displacement	• Displacements for hitting the ball or to recover position.	• In the time defined by ball trajectory.	• Out of time given by ball trajectory (late).
Outcome of the action	• Evaluation of ball trajectory.	• Impact on the displacement and action capabilities of the other player.	• Deep ball with high velocity and/or precision.
	• Moves the opponent and increases the difficulty to hit the ball.	• Short ball, slow and close to opponent position.	• Doesn't move the opponent and allow a counter-attack.

Based on the criteria for visual observation, the expert coaches made a judgment about which shot (break shot) in the sequence produced the rally perturbation that resulted in a point being lost/won (i.e., a break in game dynamics). Their identification of this information led to 100% agreement in the 28 rallies analyzed.

From the time series data produced by the digitization procedures, we determined each player's distance from the central line of the court (dcl) and the distance from the centre of the net (dn). These measures were calculated in accordance with the system of coordinates (x,y) in which the lateral displacements on the court corresponded to the x-axis, and the movements of approach and distancing in relation to the centre of the net to the y-axis. In order to identify the closest side of the court to each player at each instant, the central line of court was assigned zero coordinates by convention. For the purposes of our analysis, the left side of the court for each player was defined as the positive side, while the right hand side for each player was assigned negative values. The *goal-directed displacement index* (GDD Index) was calculated through the multiplication of the player's distance from the central line of the court (dcl) and the player's distance from the centre of the net (dn), expressed by eqn (GDD index=dcl*dn) (see Figure 1).

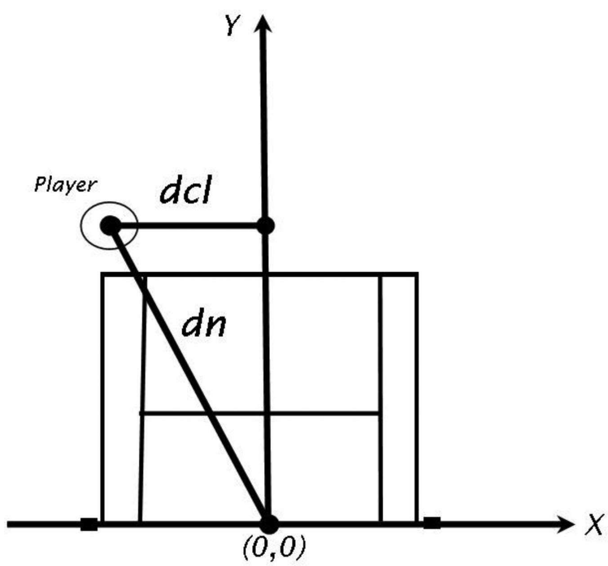

Figure 1. Schematic representation of the GDD Index proposed, which corresponds to the product between the distances of the player to the central line of the court (dcl) and to the centre of the net (dn)

In fact, the distance to the centre of the net also contains information about the lateral displacement of the player in relation to the central line. Nevertheless, due to game task constraints (e. g., field dimensions and format, the ball may bounce once on the ground, etc.), the combination between both variables (dcl and dn) allowed us to assign a measurable weight to the players' positions as a way to amplify the effect of lateral displacements over longitudinal displacements. To map the position of the players on court, the GDD index was computed, displaying positive values to the left of the central line of the court and negative values to the right (see Figure 2). As can be seen in Figure 2, each curve refers to one player and corresponds to the values that the GDD index adopted throughout the rally. The thick vertical lines represent the moments of the strokes of each player and the dotted lines the bounces of the ball on the surface. The values of the GDD index represented in x=0 refer to the position of the players during the service and the return, where the player who serves the ball is closer to the court centre (GDD Index=0), and the service-receiving player is farther away. The bold vertical line refers to the rally stroke in which a system transition that led to the winning of the point was visually identified. We aimed to verify whether the proposed variable would identify the patterns of interpersonal coordination coincident with system transitions and rally breaks identified through visual observation.

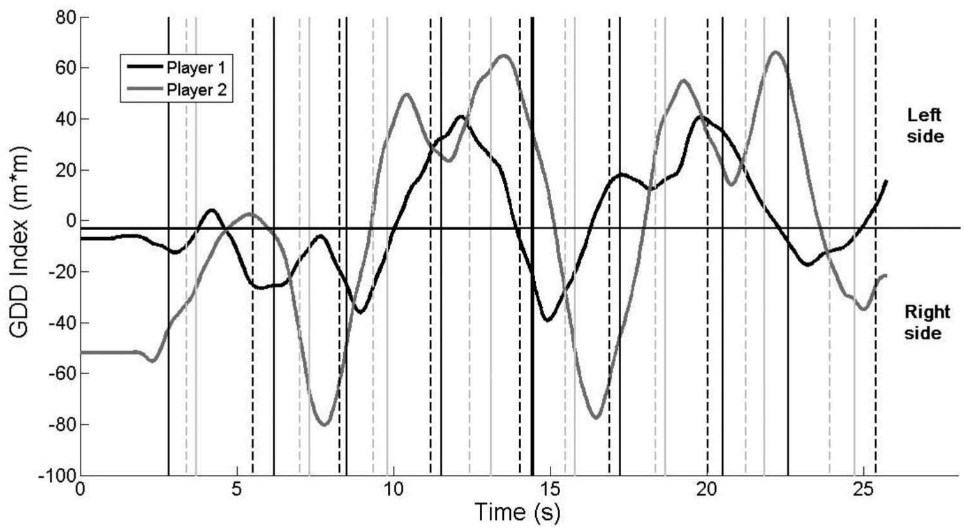

Figure 2. Exemplar data of GDD index representing the position of the players during a rally. The vertical lines represent the instants of the strokes (thick line) and of the bounces of the ball (dotted). If the players' lines are on the same side, both players are positioned on the same side of the court playing a cross-court rally. If the lines are on different sides, the players are positioned facing each other (i.e., one on the right-hand side and the other on the left-hand side of their court).

In order to statistically verify the robustness of the GDD Index to discriminate key moments of play and to identify different patterns of play, we studied the GDD index values of the situations when a player in a dyadic system of competing tennis players is moved to a location on court without being able to recover to hit the ball in time to keep the rally pace (i.e., defined here as a player 'who is disrupted'). The value of GDD Index of the player who is disrupted was considered at three distinct moments of play that can characterize dyadic system breaks: i) break shot – when the shot responsible for the rally break was made; ii) return – when the opposing player responded to an attempted break shot; iii) maximum displacement – the instant immediately after the return shot in which the GDD Index was maximum for a player. Data were subjected to a 3x2 mixed model ANOVA with a within-participant factor at the selected moments of play (break shot, return, maximum displacement), and patterns of play (angle opening and parallel variation) was the between-participant factor. Statistically significant ANOVA results were followed up with Bonferroni post hoc analyses. The level of statistical significance was set at $p < .05$. All statistical analysis were computed using SPSS® 18.0 software (SPSS Inc., Chicago, USA).

RELIABILITY

In a rally chosen at random from the 28 rallies that were analysed, the digitization process was repeated and the accuracy and the reliability of the data were evaluated through the technical error of measurement (TEM) and coefficient of reliability (*R*) [19]. The TEM revealed values in the component x of 0.02 metres (0.16%) and 0.06 metres (0.47%), and in component y of 0.01 metres (0.15%) and 0.12 metres (0.33%), in the positions of player 1 and player 2, respectively. The coefficients of reliability found in both components of both players were above R> .999.

RESULTS

PATTERNS OF INTERPERSONAL DYNAMICS

The visual inspection of the GDD index across time in the 28 rallies that formed the data sample allowed us to identify important aspects about the emergent dynamics of dyadic system interactions during competitive performance. Whenever the two curves are both above or below zero, the players are playing in a cross-court pattern (using two coordinate systems, both players are on their left or right court side). If the values are negative for both players, there exists a right-hand side cross-court pattern (if the players are right handed they are playing with a forehand stroke, Figure 3a). When both curves display positive values, there exists a left-hand side cross-court pattern (if the players are right handed they are supposedly playing with a backhand stroke, Figure 3b). Likewise, when the curve that represents one of the players displays positive values and the curve for the other player presents negative values, then they are positioned on opposite sides of the court, which is facing each other (long line rally, Figure 3c).

RALLY BREAKS

Through comparison of the behaviours observed on video and the values of the GDD index over time during performance, we identified two patterns of coordination which allowed one of the players to gain an advantage over the other: angle opening and parallel variation.

The angle opening pattern of coordination is characterised by an increase of the distance of one of the players to central line while the other maintains a stable position in relation to this line. With the increase of the distance of one of the players in relation to the central line above a critical limit, which can vary in each rally and between each individual, existing system order is changed and the player who is being displaced cannot regain a position to cover the space on court. In the example presented in Figure 4, from the third stroke of player 1, both players tried to displace the opponent laterally to the left. This increasing lateral drift of both players allowed player 1, in the fifth stroke, identified by the experts as the break shot, to move player 2 laterally out of the court. At the moment of play defined as displacement, the player showed a GDD Index of 98.44 (corresponding to more than 1 m to the left-hand side of the doubles sideline), not allowing him to recover in time (an empty space was created on the right-hand side of the court).

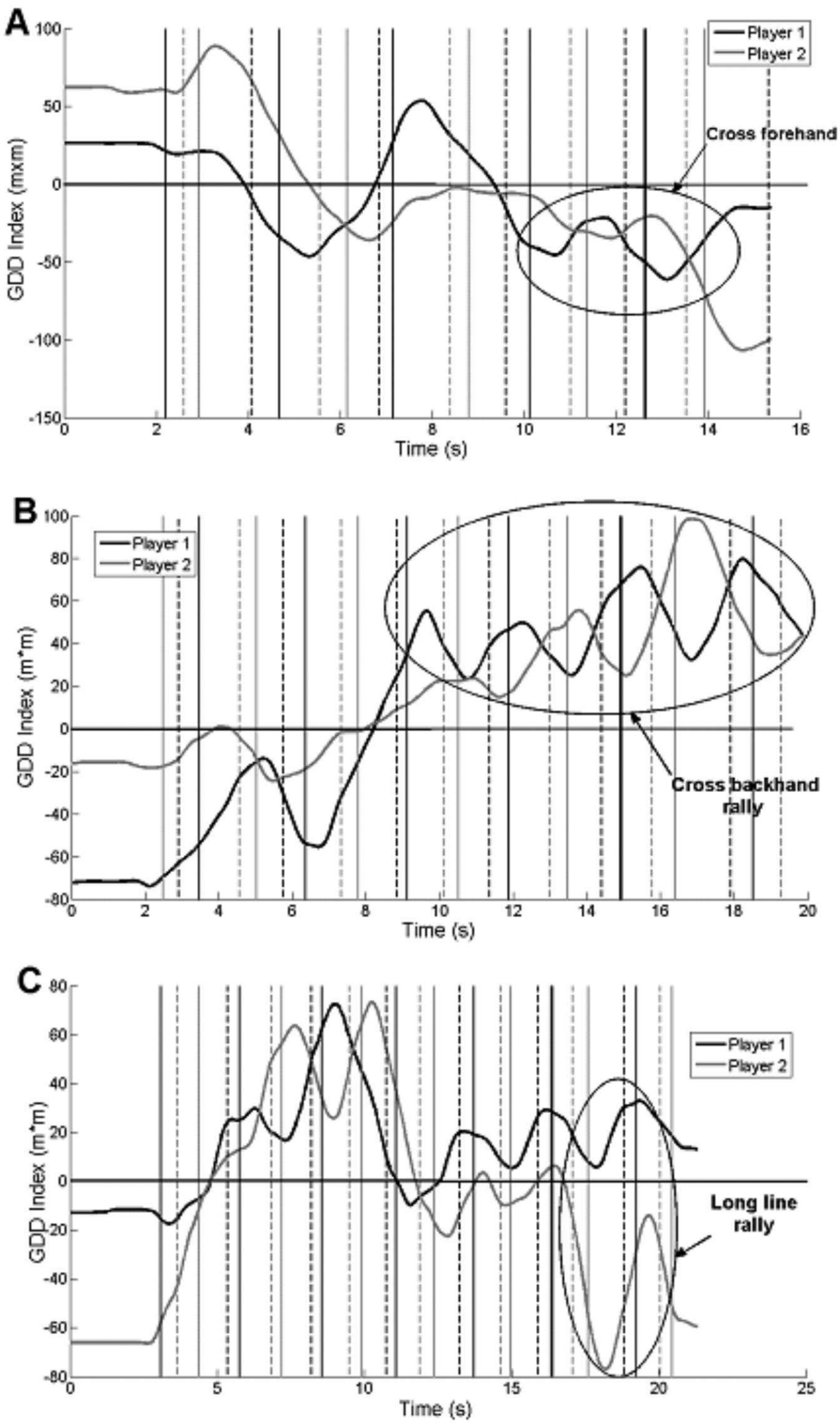

Figure 3. Exemplar patterns of interpersonal dynamics for different rallies. Inside of circle three patterns are identified: A) cross-court forehand exchange; B) cross-court backhand exchange and; C) exchange with players facing each other.

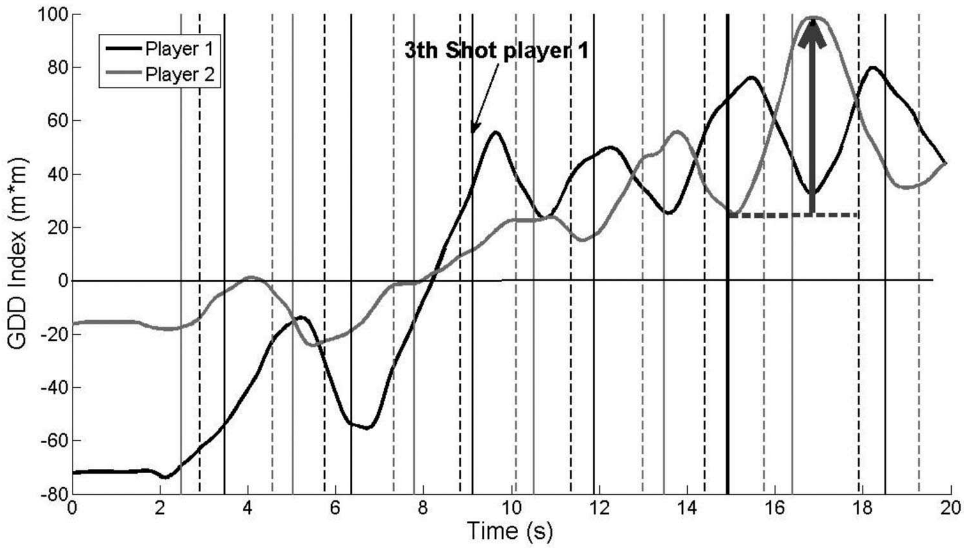

Figure 4. Example of a transition situation involving an angle opening during a cross-court backhand rally. Player 1 in the fifth stroke compels player 2 to increase his index from GDD=20 to GDD=98 by moving laterally out of the court, opening a lot of space on the right-hand side of his court for a counter attack of player 1.

In the parallel variation measure, a change in system symmetry was achieved through the displacement caused by the shot down-the-line. As exemplified in Figure 5, from the third and fourth strokes of player 2 there were two unsuccessful attempts to induce instability in the spatial-temporal interaction between players by using parallel variation shots. First, player 1 was displaced from the left side of the court to the right side and then from the right side to the left side. After recovering his position, at the sixth stroke (identified as the break shot by experts) player 1 made a parallel variation that led to a transition which resulted in a rally break. The break shot forced player 2 to displace from the left to the right-hand side of the court, with a GDD Index of + 27.1 that changed to a value of - 63.9 at the instant of return and a GDD Index=- 86.1 for displacement. Larger values of the GDD index at the moment of displacement indicated that this situation was advantageous for player 1 because it allowed exploiting the empty space on the left-hand side of the opponent's court to score the point. Moreover, the dyadic system break was confirmed by the lower distance value of player 1 to the centre of the court in relation to player 2 at the seventh shot (GDD Index = -4.1 and GDD Index = -39.4).

Figure 5 reveals that the index value of player 2 continued to increase after his sixth stroke (shot return), which indicated that after that stroke, player 2 moved away laterally from the central line. The identification of the sixth stroke of player 1 is a critical moment (i.e., break shot) in the dynamics of this rally, based on the analysis of the index proposed, because it coincides with the stroke that was considered by the experts as responsible for creating a system break. This relation occurred in 26 of the 28 rallies that were analysed (93%), possibly due to the combined effect of different strokes or to the exceptional merit of a stroke, and was not as clear in the remaining rallies.

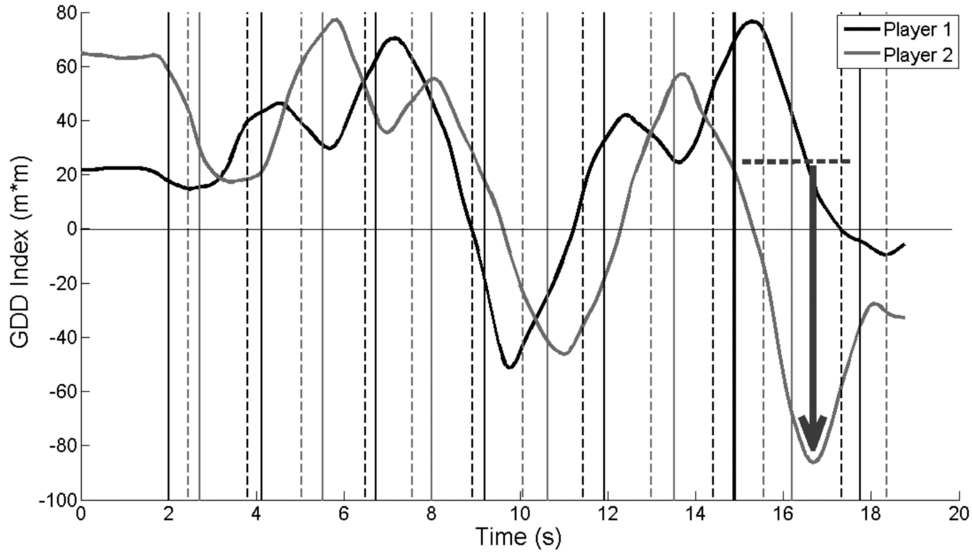

Figure 5. Example of a rally break involving parallel variation. Player 1 in his sixth shot makes a parallel variation with a backhand down-the-line that compels player 2 to make a major move from the left-hand side to the right-hand side of his court. After this time, both players are playing facing each other and when player 1 hit the next shot he is closer to the centre of the court and/or of the baseline.

Statistical analysis confirmed the results of visual inspection. We observed a main effect for moments of play, $F(2,50) = 91.64$, $p < .001$, $h^2 = .786$ and for patterns of play $F(1,25) = 17.44$, $p < .001$, $h^2 = .411$. A significant interaction was also observed between the moments of play and the patterns of play, $F(2,50) = 3.59$, $p = .035$, $h^2 = .125$. As expected, post hoc comparisons on moments of play revealed significant differences between the three moments of play ($p < .001$), with the break shot presenting low values ($M = 26.76$, $SD = 14.46$), followed by return ($M = 51.88$, $SD = 20.13$) and finally by maximal displacement ($M = 77.29$, $SD = 22.06$). The two moments of play return and displacement that expressed the effect of the attack on spatial-temporal balance between players presented larger GDD index values for angle opening than for parallel variation patterns of play. The moment of play break shot did not reveal significant differences between angle opening and parallel variation patterns of play (see Table 2).

Table 2. Comparison between patterns of play for each moment of play

			Patterns of play		
			Angle opening	**Parallel variation**	
Moments of play	Break shot	Mean	29.91	21.89	p > .05
		SD	14.03	14.39	
	Return	Mean	61.14	36.16	p < .001
		SD	18.23	11.96	
	Maximum displacement	Mean	88.21	60.42	p < .001
		SD	18.93	15.29	

DISCUSSION

The objective of this study was to analyse the coordination tendencies that emerged between the players during a rally from behind the baseline during competitive tennis performance. For that purpose we developed the GDD index. This measure simultaneously considered the distancing of the players in relation to two on-court reference points during competitive performance: the central line of the court and the centre of the net. The graphical representation of this index enabled identification of different patterns of action and rally break situations that expressed the tactical behaviours of the players. Statistical analysis revealed that GDD index's values discriminated the key moments of play and different patterns of play of the player who is disrupted. The values of GDD index of the player that is being unbalanced significantly increased after the break shot indicating a dyadic system break. The significant differences found between the two patterns of play, parallel variation and opening angle, for return and maximum displacement moments, indicated that a player's advantage over the other emerged from different spatial-temporal relations.

RELATIVE POSITION OF THE PLAYERS ON THE COURT

In our results, analysis of movement displacements during the approach and away from the centre of the court expressed the different functional relations that can be established between competing players. It allowed us to identify two types of relational behaviours typical in tennis. These relations emerged when opponents are facing each other on opposite sides of their respective court area or playing cross-court, which are relevant to the interpretation of the relative phase values observed in previous studies of tennis [3, 6, 13]. The data reported here have improved understanding of why and how players can destabilise a rally sequence with an opponent, with reference to their position on court. The obtained results allow us to explain that the stability of the interactions between players was highly constrained by the position of the players (near or away from the central line of the court) and the pattern of interactions developed during play (cross-court or down-the-line rallies). However, the spatial-temporal coordination between the two players revealed higher levels of stability when one player moved away from the central line of the court to hit the ball and, while the other player was approaching the central line of the court to defend his court. Assuming a reference of two coordinate systems, if the players were playing a cross-court rally they would be moving in opposite directions (anti-phase mode). If they were playing a down-the-line rally, they would be moving in the same direction (in-phase mode). Conversely, if both players were approaching or moving away from the central line of the court this relationship would signify the existence of instability in the game context. Whenever the players were moving away from the more stable modes of coordination a system perturbation or rally break may emerge. It was possible to verify that some variations in the measured parameters did not change the system stability between players. In other cases variations in the same parameters, but of higher magnitude, promoted an abrupt change in the players' spatial-temporal relations. In this sense, it seems that the GDD Index can be used to determine the critical values that are associated with breaks in the mode of coordination between competing players in tennis.

An innovative aspect of this study is that our analysis offers a captured weight to the players' positioning on court with reference to their longitudinal and lateral displacements. This approach will allow us to interpret patterns of play in matches, the situations of system transition that occur most often, in different performance conditions, relative to the positioning of players on court. For example, it might be possible to understand whether the positioning of a specific player, when displaced laterally or longitudinally to one side beyond a critical threshold value, would allow an opponent to advance on court and control the game tactically. Similarly, understanding would be gained of when displacement of a player to the right- or left-hand side of the court, above a critical threshold value, might lead to transitions in a rally, with a parallel variation being created. This information would provide an invaluable source of information for competitive performance preparation. This index measure may be used to determine the critical values that are associated with breaks in the mode of coordination between competing players. However, further research is needed to consider the direction of the displacement and also the movement of players towards or away from the central line of the court and the net on emergence of interpersonal patterns of coordination in tennis.

APPLICATIONS TO TRAINING

The demonstration of the sensitivity of the GDD index to a range of values associated with different transition situations during competitive performance, suggests that it may be a valuable tool for diagnosis, prescription and control of training exercises. In performance diagnosis, for example, if a player often loses a point through an opening angle or by a parallel variation situation with a displacement moment GDD Index below a certain threshold value (a critical mean value associated with each game situations determined by analyzing several games), it could imply that the player's displacement ability on court needs to be improved. At the level of prescription of training exercises, the index could help to scale areas on court in relation to the position of an opponent that might promote transition situations during performance. Those zones can be created on the court (see A zones in Figure 6), according to individual values of the GDD index while considering the intended position of the opponent to promote a specific transition. For example, the coach can introduce a constraint on players' behaviours during practice by not allowing the ball to bounce in the centre of the court in order for players to exploit a parallel variation or an opening angle action (see B zones in Figure 6, situation 1). In contrast, introducing a constraint to rebound the ball to the centre of the court and near the baseline can help players to improve their ability to move opponents away from the baseline (see B zones in Figure 6, situation 2). Finally, monitoring changing values of the index allows us to evaluate the effect of the training process that is being implemented.

CONCLUSION

In this study, we proposed an empirical function that captures the spatial-temporal relationship between tennis players during competitive performance. This parameter, termed the *goal-directed displacement index* (GDD Index), is defined over time by the product of both players' distances to the central line of the court and to the centre of the net. It quantitatively describes how stable modes of coordination (order) and periods of disorder arise, as well as transitions that lead to the winning of a point or to the emergence of new states of order in a rally from behind the baseline. Results showed that the GDD index successfully described different tennis players' patterns of interaction (cross and down-the-line rallies), as well as identifying breaks in patterns of play during competitive performance (parallel variation and angle opening), due to changes in relative positioning on court.

Finally, this parameter could provide new avenues for developing practical understanding of competitive performance in tennis. The elaboration of individual profiles of play, using the GDD index, could also improve performance analysis in tennis.

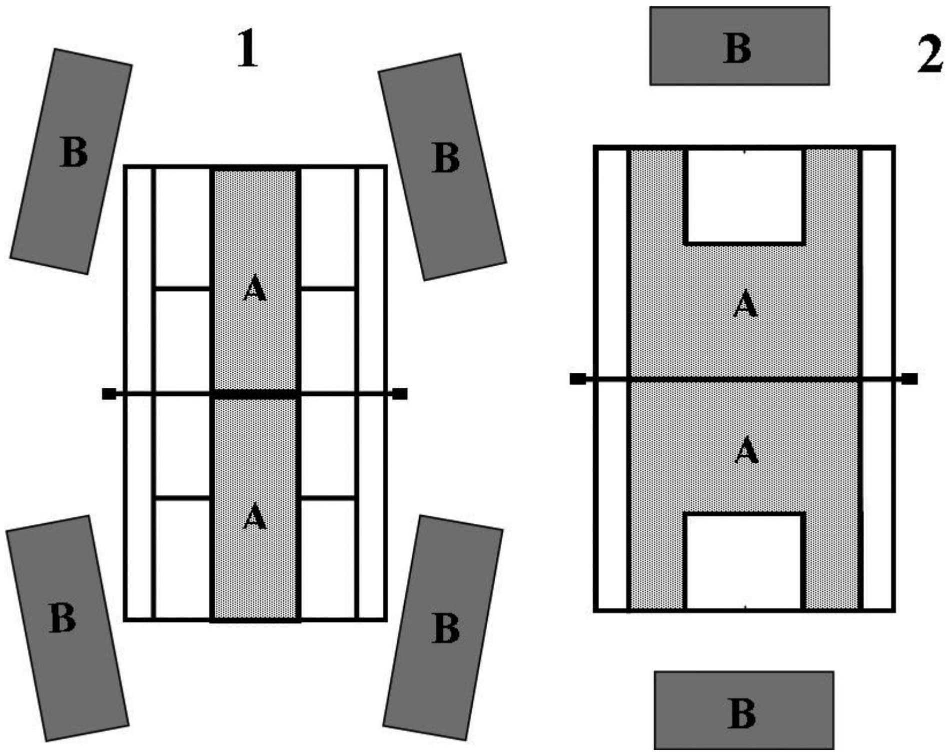

Figure 6. Example of two conditions considering opponent position and game zones that allow players to explore the different transition situations during performance: A - zones where ball is not allowed to bounce; B - areas to place the opponent

REFERENCES

1. O'Donoghue, P., Performance Models of Ladies' and Men's Singles Tennis at the Australian Open, *International Journal of Performance Analysis in Sport*, 2002, 2(1), 73-84.
2. O'Donoghue, P. and Liddle, S.D., A Notational Analysis of Elite Tennis Strategy, *Journal of Sports Sciences*, 2001, 19, 107-115.
3. Palut, Y. and Zanone, P., A Dynamical Analysis of Tennis: Concepts and Data, *Journal of Sports Sciences*, 2005, 23(10), 1021-1032.
4. McGarry, T. and Franks, I., A Stochastic Approach to Predicting Competition Squash Match-Play, *Journal of Sports Sciences*, 1994, 12, 573 - 584.
5. McGarry, T. and Franks, I., Analysing Championship Squash Match Play: In Search of a System Description, in: Haake S., ed., *The Engineering of Sport*, Balkema, Rotterdam, 1996, 263-269.
6. Lames, M., Modelling the Interaction in Game Sports–Relative Phase and Moving Correlations, *Journal of Sports Science and Medicine*, 2006, 5, 556-560.
7. McGarry, T., Anderson, D., Wallace, S., et al., Sport Competition as a Dynamical Self-Organizing System, *Journal of Sports Sciences*, 2002, 20(10), 771-781.
8. Fajen, B.R., Riley, M.A. and Turvey, M.T., Information, Affordances, and the Control of Action in Sport, *International Journal of Sport Psychology*, 2009, 40(1), 79-107.
9. Passos, P., Araújo, D., Davids, K. et al., Information-Governing Dynamics of Attacker-Defender Interactions in Youth Rugby Union, *Journal of Sports Sciences*, 2008, 26(13), 1421-9.

10. Kelso, J.A.S., *Dynamic Patterns: The Self-Organization of Brain and Behavior*, The MIT Press, Cambridge, MA, 1995.

11. Rosenblum, M., Pikovsky, A., Kurths, J. et al., Phase Synchronization: from Theory to Data Analysis, in: Moss F.and Gielen S., eds., *Handbook of Biological Physics*, Elsevier Science, 2001, 279-321.

12. McGarry, T., Applied and Theoretical Perspectives of Performance Analysis in Sport: Scientific Issues and Challenges, *International Journal of Performance Analysis in Sport*, 2009, 9(1), 128-140.

13. Walter, F., Lames, M. and McGarry, T., Analysis of Sports Performance as a Dynamical System by Means of the Relative Phase, *International Journal of Computer Science in Sport*, 2007, 6 (2), 35-41.

14. Crespo, M. and Miley D., *Advanced Coaches Manual*, International Tennis Federation (ITF Ltd), London, 1998.

15. Duarte, R., Araújo, D., Fernandes, O. et al., Capturing Complex Human Behaviors in Representative Sports Contexts With a Single Camera, *Medicina*, 2010, 46(6), 408-414.

16. Fernandes, O., Folgado, H., Duarte, R. et al., Validation of the Tool for Applied and Contextual Time-Series Observation, *International Journal of Sport Psychology*, 2010, 41(4), 63-64.

17. Abdel-Aziz, Y. and Karara, H., Direct Linear Transformation from Comparator Coordinates into Object Space Coordinates in Close-Range Photogrammetry, in: *Symposium on Close-Range Photogrammetry*, American Society of Photogrammetry, Falls Church, VA, 1971.

18. James, N., Taylor, J. and Standley, S., Reliability Procedures for Categorical Data in Performance Analysis, *International Journal of Performance Analysis in Sport*, 2007, 7(1), 1-11.

19. Goto, R. and Mascie-Taylor, C., Precision Measurement as a Component of Human Variation, *Journal Physiological Anthropology*, 2007, 26(2), 253-256.