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# Prospective information for pass decisional behavior in rugby union

Vanda Correia<sup>a,\*</sup>, Duarte Araujo<sup>a</sup>, Cathy Craig<sup>b</sup>, Pedro Passos<sup>a</sup>

<sup>a</sup> Faculty of Human Kinetics, Technical University of Lisbon, 1495-688 Lisbon, Portugal

<sup>b</sup> School of Psychology, Queen's University Belfast, Northern Ireland

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### ABSTRACT

Decision-making requires the perception of relevant information variables that emerge from the player–environment interaction. The purpose of the present article is to empirically assess whether players' decisional behavior about which type of pass to make is influenced by the spatio-temporal variable tau. Time series positional data of rugby players were analyzed from video footage taken in real match scenarios. The tau of the distance motion gap between attacker and defender was calculated, along with the duration of the next pass. Results revealed that the initial tau value predicted 64% of the variance found in pass duration. A qualitative distinction of tau dynamics between two periods of the approach between the attacker and the defender was also observed. We argue that the time-to-contact between the attacker and the defender may yield information about future pass possibilities. Additionally, the informational fields constraining attacker–defender interaction may be viewed as a convergent channeling of possibilities towards a single pass solution.

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## 1. Introduction

Since Gibson's (1966) conception about the reciprocal relationship between information and action in human activity, numerous researchers have integrated it into perception and action studies. In particular, the field of sports related research has a few empirical studies that use the ecological approach as a means of understanding sports performance (e.g., tau guidance in golf putting, Craig, Delay,

\* Corresponding author. Tel.: +351 214149209.

E-mail addresses: [advcorreia@fmh.utl.pt](mailto:advcorreia@fmh.utl.pt), [correia.vanda@gmail.com](mailto:correia.vanda@gmail.com) (V. Correia).

Grealy, and Lee (2000); optical information pick-up in basketball jump shooting, Oliveira, Oudejans, and Beek (2006); information-based decisional dynamics; Araújo, Davids, and Hristovski (2006)). However, these studies are rare, and are hardly ever conducted with interacting athletes, and in actual competitions. The present study aims to give some input to the understanding of how information is guiding rugby players' action while performing in a real game scenario. Reading the findings of a range of sports research on perception and action from an ecological dynamics perspective (Araújo et al., 2006), decision-making can be regarded as emerging from constraints in the player–environment interaction that push the players to pick up informational variables about the possibilities for action afforded in the unfolding dynamics in order to accomplish performance goals. Decision-making comprises the particularities of transitions in the courses of action, based on the detection or selection of a new affordance. Moreover, perception of an affordance, taking into account its dynamic nature, underlies the prospective control of behavior (Fajen, Riley, & Turvey, 2009; Turvey, 1992).

Information is understood as being directly available and displaying the environment of performance properties and what they afford to the player(s) (Gibson, 1979/1986). Following an ecological dynamics perspective, which holds that the evolving interdependence between actions in the dynamical interactions between players and environment (Araújo et al., 2006), this study aims to investigate the informational influence of the closing gap between an attacker and an approaching defender on the attacker's decision to pass.

Dyadic synergies, in the form of attacker–defender interactions, can display non-linear properties (Araújo et al., 2006; Davids, Button, Araújo, Renshaw, & Hristovski, 2006) and be regarded as complex systems. Decisions and actions of the dyadic sub-systems of team sports are externally regulated by boundaries of the information fields geared by constraints, such as interpersonal distances among players, border line markings, dimensions, and rules of the Rugby game (Passos et al., 2008). Random interactions between system components (e.g., players in a dyad) can change into more organized forms of interactions, as a single key system parameter changes in value (e.g., changes in players' relative velocity). But these changes only condition the attacker–defender dyadic system behavior when entering in regions of self-organized criticality (e.g., within 4 m of interpersonal distance as suggested by Passos et al., 2008).

### *1.1. Prospective information unfolding players–environment interaction and decisional behavior*

Prospective control is a straightforward ecological aspect of human behavior. In essence it is the perception of the flowing relationship between the individual and the environment that allows goal-directed action to be updated constantly and ahead of time. Variability and instability are game features, and pre-established game plans and strategic decisions appear unlikely to be the main influence on a player's decisional behavior in the actual game. In fact, players must be able to perceive the game, and to prospectively perceive its ongoing dynamics in order to achieve their (and the team's) goals. Instead of simply reacting to what happens, to rely solely on memory and cognitive inference processes, which would disregard the evidence of the changing interactive nature of the surrounding environment, action must mostly be dynamically controlled ahead of time by picking up relevant prospective information. Consistent with this view are studies by (Craig, Berton, Rao, Fernandez, & Bootsma, 2006; Craig et al., 2009) that showed how the continuous non-linear change in the direction of a ball's flight, caused by the Magnus force, influenced expert goalkeepers' ability to accurately perceive the ball's future arrival point. These authors considered that movement during interceptive actions is better characterized by a reliance on prospective information carried in the perceptual flow than on computation-based extrapolations of the current situation (Craig et al., 2006).

As Turvey (1992) put it, when “positioning oneself to receive a pass in a game of football, it is essential to see what movements are possible, what encounters are possible, and to control behavior accordingly” (Turvey, 1992, p. 174). Likewise, to adequately guide the approach towards a defender while receiving the ball from a teammate and then passing it away for another attacking support player, prospective information is needed. Successful performance requires that the player is attuned to relevant information unfolding during such game interaction and detects and uses this information

to guide action to achieve performance goals (Araújo, Davids, & Serpa, 2005). In keeping with this, that is to say that in a rugby game the player must act to pick-up information in the game, and the information he/she picks up allows him/her to act, the aforementioned interaction enters this continuous perception–action loop.

For the prospective control of action, Lee (1998) considered that all goal-directed movement (e.g., upcoming collisions: Bootsma & Craig, 2003; attacking forehand drives in table tennis: Bootsma & van Wieringen, 1990) requires the prospective guidance of the closure of *motion gaps*. A motion gap is any gap between a measurable current state and a goal state (Lee, Craig, & Grealy, 1999; Trevarthen, 2007). In this manner, prospective control of these gaps means that there is information about the way the gap is closing that can be extrapolated into the future and can be used to adjust and control online goal-directed action (Lee et al., 1999). *Tau of a motion gap* ( $t(x)$ ) specifies the time that gap would take to close if the rate of closing were kept constant (Lee, 1998; Trevarthen, 2007; von Hofsten, 2007). Therefore, it specifies both spatial and temporal information. Furthermore, though materialized as a ratio function between the current size of the motion gap ( $x$ ) and its current rate of closure ( $\dot{x}$ ), Lee (1998) emphasized that it is directly perceivable without the prior need to enter and compute  $x$  and  $\dot{x}$  (see also, Kim, Turvey, & Carello, 1993). Hence, according to Lee et al. (1999) the control of these motion gaps is founded on the principle that the relevant information encapsulated in the *tau* of that motion gap can be picked up through changes in the sensory array and allows for the actor to adjust the way the gap is closing to achieve the desired goal. One important aspect is that it is regarded as what the individual perceives for “timing actions relative to the environment” (Trevarthen, 2007, p. 7). A correspondence between this timing of specific actions with specific tau-margin values has been empirically evidenced in sports research (e.g., hitting an accelerating ball by Lee, Young, Reddish, Lough, and Clayton (1983)). For instance, Bootsma and Craig (2003) showed in a collision judgment task that these judgments were prospectively guided by tau information. These authors assumed that their findings pointed towards the participants’ sensitivity to the evolution of tau over time ( $\Delta\tau$ ). With respect to the team sport of rugby, tau has been recently considered as a candidate informational variable that can be used to control a player’s action during typical game situations (e.g., gap “passability”, Watson & Craig, 2008; detecting deceptive movement, Brault, Bideau, Craig, & Kulpa, 2010).

Likewise, the study of Passos and colleagues (2008) may be regarded as supporting the view of tau influencing players’ actions. This is because the parameters (interpersonal distance and relative velocity) driving the identified organizational states of attacker–defender dyads (i.e., try or tackle) are inextricably tied up in the tau variable.

Along these lines, the approximation between attacking and defending players and the subsequent pass is not expected to be controlled by means of processing spatial information variables, and computing and monitoring the velocities to achieve a distance value in order to fit a programmed pass to a teammate. Instead, this approximation and the ensuing behavior are regarded as being directly guided by the spatial/temporal information specified by *tau* (Lee, 1980). Even though some researchers have been probing the information guiding action in sport, hardly any have attempted to identify information that players may be attending to during decision-making performance in an actual game. Focusing on specific game situations of the actual match, such as second phases-of-play in which the two sequential passes are made successfully, the hypothesis on the basis of this study was that a relationship might exist between the information specifying time-to-contact with an approaching defender (i.e., tau of this closing distance motion gap) and the prospective control of the type of pass executed.

Accordingly, the present study intended to identify the way a particular informational variable such as *tau* might be used to guide action in the game of rugby. However, the purpose was not to identify *the* informational variable being used by players, but rather to identify *one of the* potentially relevant variables available in the interaction between the players and the environment in an actual game. This question has also practical value, since it takes into account the construction of representative task designs (i.e., tasks that represent the conditions towards which the experimental or practice results are intended to apply; Araújo, Davids, & Passos, 2007; Brunswik, 1956) both in research (in the design of experimental tasks), and in practice (to define practice task constraints) to study/develop perception–action coupling.

## 2. Methods

### 2.1. Data/sample

To constitute the sample for this preliminary study, 13 video scenes of rugby second phases-of-play near the try line were selected from actual rugby union matches.

The criterion used for match selection was to include only those matches played by the “best” teams (according to previous classifications in this championship), and where there was an “expected equilibrium” between the performance of both teams involved in each match. Therefore, the matches analyzed were the semi-finals and the final male senior matches of both the Portuguese Premier League Championship, and the Portuguese Cup (2007–2008 season). For scene selection three criteria were used. The first was to consider those scenes where the attacking team was playing in the opponent’s half pitch within the 22 m area, i.e., between the try line and the 22 m line (situations that precede the possibility of a try being scored). Second, only second phases-of-play were considered given the less ruled constrained onside position. By second phase-of-play we mean all open play following a ruck or a maul. Conversely, first phase-of-play or set plays, comprise all the restarts of play following a scrum, line-out, drop-out or free kick (for a detailed description of this game stoppages see the [International Rugby Board, 2010](#)). While in the first phases players are initially positioned beyond an offside line greatly distanced from the game stoppage line (i.e., 10 m behind the touchline in the line-out and 5 m behind the backfoot of the last player in a scrum, cf. [International Rugby Board, 2010](#)), in second phases-of-play the onside position is much less constrained (i.e., the offside line runs from the backfoot of the last player in either the ruck or the maul, cf. [International Rugby Board, 2010](#)). This difference counts for higher variance in the initial distance of the approach run between attackers and defenders in subsequent open play thus is in line with this study’s purpose. Third, given the aim of investigating the information underlying a successful attacking behavior, only phases that ended with an effective pass to a teammate were considered, that is to say, passes in which the attackers passed the ball and the receiver caught the ball. Additionally, it is worth noting that the selected scenes were taken without making distinction on characteristics of the approach between players (e.g., initial distance, players’ velocity of approach), nor on the subsequent pass type (e.g., long, short), nor on whether it was made by different players. The 13 scenes considered were all the that accomplished the just mentioned criteria, in the high-level matches mentioned before.

The matches were recorded using two digital video cameras (Canon HDV-20 and Panasonic NV-GS21) each facing each half of the rugby pitch. The selected footages (sampled at 25 Hz) were digitized using TACTO software (for software details see [Duarte, Ferreira, Folgado, & Fernandes, in press; Fernandes, Folgado, Duarte, & Malta, in press](#)) that allowed us to obtain the players’ relative positions as pixel coordinates over time. The time series of pixel coordinates were afterwards transformed into real coordinates by means of Direct Linear Transformations method (2D-DLT) using Matlab 7.0 software. The data were analyzed in a  $xy$ -coordinate system with the  $x$ -axis corresponding to the rugby pitch’s touch line and the  $y$ -axis the try line. From these time series positional data (real coordinates) the target parameters of analysis were computed.

### 2.2. Variables

For the purposes of the present study the movement analysis included the time series positional data of: (a) the first attacking player who received the ball (first receiver) from the onset of the second phase-of-play (i.e., play immediately following a ruck or a maul) and made an intentional and accurate pass, (b) the defending player (defender) marking the first receiver, and (c) the attacking player (second receiver) who received the ball from the first receiver. The time period considered as the key period of approach where the gap was closing between the attacker (i.e., the first receiver) and the defender began when the first receiver got the ball and lasted until he passed the ball to the second receiver.

According to [Lee \(1980\)](#) as tau informs us about how a motion gap is closing it can also be regarded as affording information about a future course of action. The motion gap under analysis in this case

was the distance motion gap between the first receiver and the defender (in the  $x$ -axis only). This distance motion gap was calculated using the time series positional data of these players, in each frame of the period of approach. The tau of this closing distance gap was obtained for each frame of the same data period by applying Lee's (1980) formulae of tau ( $\tau(x) = x/\dot{x}$ ), which concerns the ratio of the current size of the motion gap,  $x$  (i.e., the distance between first receiver and direct defender) and its current rate of closure,  $\dot{x}$  (i.e., the instantaneous velocity of this approach between players). Negative tau values mean that the motion gap is closing, with tau being the first-order time-to-closure.

### 2.2.1. Approach variables (candidate informational variables)

For this study, the tau values of the closing gap between the attacker and defender that were considered are: (i) the initial value of tau, when the first receiver gets the ball at the onset of the second phase-of-play, (ii) the final value of tau, just before the ball has left this attacking player's hands, and (iii) mean tau, calculated as the mean of tau values during the approach between these players.

The following analysis mainly focuses on the relation of tau variables with pass related variables, but also of other variables potentially influencing the decision outlined in this triad subsystem "first receiver" – "defender" – "second receiver". Therefore, alongside tau variables other kinematic discrete variables of the attacker–defender approach were also analyzed, such as the (i) initial distance between the first receiver and the defender, obtained by the difference in the  $x$ -coordinate of the first receiver at the first frame of ball possession and the  $x$ -coordinate of the defender at the corresponding frame of the positional data time series, and (ii) motion gap duration, measured as the length of time elapsing during the approach of the defender towards the first receiver and while the first receiver is in possession of the ball.

### 2.2.2. Pass variables (action variables)

The pass variables considered (regarded as means differentiating the type of pass) were discrete measures of: (i) pass distance (see Fig. 1) that was obtained by subtracting the difference in the  $y$ -coordinates of the first receiver at the last frame of ball possession and the  $y$ -coordinates of the second receiver player at the first frame of ball possession; (ii) the pass duration that was operationalized as the length of time taken for the pass (or ball flight time), and it was measured from when the ball leaves the hands of the first receiver until the instant it arrives in the second receiver's hands; (iii) the pass angle (Fig. 1), which was measured at the moment of the pass (when the ball leaves the first

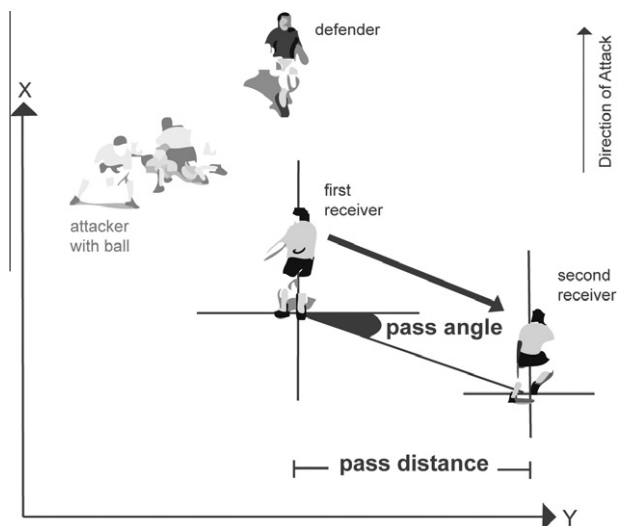


Fig. 1. A schematic representation of pass distance and angle in a second phase-of-play.

receiver's hands), and was defined between a line that crossed the  $x$ -coordinates of the first receiver and the position where the ball arrives with the pass at the second receiver; and (iv) the pass velocity was obtained by calculating the first time derivative of ball flight (i.e., pass velocity = pass distance/pass duration). The classification of pass (as short or long passes) by means of these variables can also be found in the rugby literature (Biscombe & Drewett, 1998).

### 2.3. Data analysis

The variables emerging in the approach between the first receiver and the nearest defender (i.e., initial, final and mean tau, motion gap duration, and initial distance attacker–defender), were regarded as potential spatial–temporal candidate variables informing players about what action to take next, more specifically informing decisions about the type of pass to make given the ensuing situation.

The degree of the relationship between the informational variables and the pass variables was tested with the parametric Pearson Product Moment correlation. In order to assess the nature of the relationship between pass variables (cf. Bhattacharyya & Johnson, 1977) considered as dependent variables and approach variables (informational variables), that are potentially independent or predictor variables, a linear regression analysis was also performed.

Another aspect that we considered for analysis was the variability in tau between the situations under scrutiny in this study (inter-trial variability) during the attacker–defender approach. Variability was considered not only after the former received the ball (the motion gap considered), but also in the approach before this first pass was received. This tau variability over time was calculated by means of the continuous method of multiple-situation variability, the point-by-point variability band (James, 2004). This method involves the computation of the mean and standard deviation for each corresponding data point (each frame = 0.04 s) of the tau series across the situations under analysis. For the purpose of this analysis, we considered the last 18 data points (one data point per frame) of the approach “Without the ball” (i.e., just before the 1st receiver gets the ball), and the 12 data points of the approach “With the ball” (i.e., just after the first receiver gets the ball). The criteria used to set these points' boundary for each period was to comply with the mean percentage of points corresponding to each period for all the trials ( $N_{\text{approach “Without the ball”}} = 13$ ,  $M_{\% \text{ data points}} = 60$ ,  $SD = 10\%$ ;  $N_{\text{approach “With the ball”}} = 13$ ,  $M_{\% \text{ data points}} = 40$ ,  $SD = 10\%$ ). The tau point-by-point variability band is thus formed by the outcome single value for each group of data points representing an instant in time (James, 2004). In addition, in order to quantitatively assess the differences between the two periods of approach in the point-by-point mean tau analysis, the Wilcoxon signed rank test was performed.

Intra-trial tau dynamics were assessed individually by graphical inspection using the same criteria used in the point-by-point variability method to set the points' boundary considered in each period. Moreover, we assessed whether the two periods of approach (“Without the ball” and “With the ball”) showed differences in the evolution of tau by performing a Wilcoxon signed rank test on the slope of the trend line corresponding to each period data point, which was considered to reflect how tau changes over time.

## 3. Results

### 3.1. Distance motion gap

For the entire sample, we calculated the longitudinal distance motion gap (i.e., considering the field lateral line as the  $x$ -axis of reference) between the attacker and the defender. As expected, it was shown that it decreases over time (see Fig. 2), indicating that the players are getting closer to each other through the closing of this distance motion gap.

### 3.2. Informational variables and pass variables

Pearson's correlation tests showed significant negative correlations between pass distance and the initial tau value of the motion gap and also between pass duration and the initial tau value of the

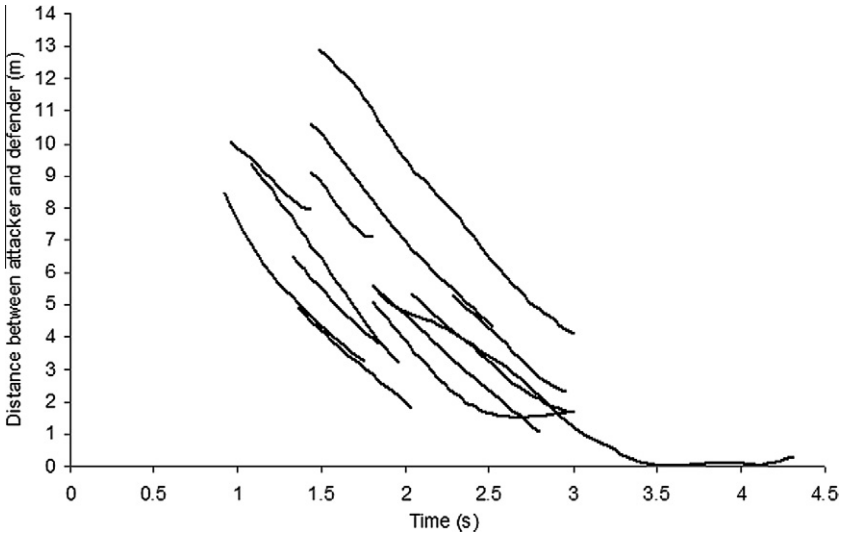


Fig. 2. Distance between the first receiver (with ball) and the marking defender over time for all the analyzed trials (N = 13).

motion gap ( $r_p = -.795, p = .001$ , and  $r_p = -.802, p = .001$ , respectively). Likewise, a significant negative correlation was also found for pass distance and the mean tau of the distance motion gap representing the approach between the first receiver and the defender ( $r_p = -.58, p = .036$ ). No significant correlation was however found between all the other pass variables and informational variables, such as the final tau value, initial approach distance, and motion gap duration ( $p > .05$ ).

Given that pass distance and pass duration are highly correlated ( $r_p = .85, p < .000$ ), defining both the type of pass made, we opted to perform a regression analysis with only the pass duration. The results leaned towards a linear relation between pass duration (dependent variable) and initial tau (independent variable) ( $R^2 = .64; F = 19.79, p < .001; \beta = -.43, \alpha = -.18, p < .001$ ) as shown in Fig. 3.

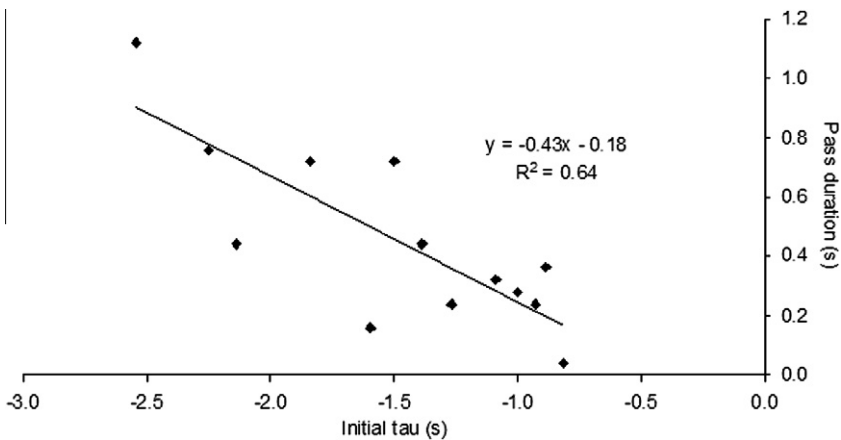
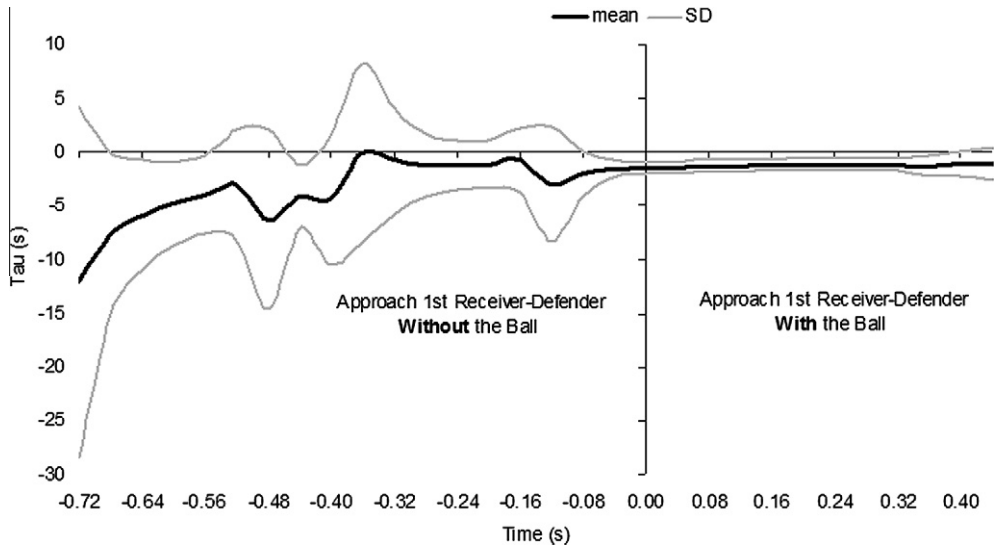


Fig. 3. Dispersion diagram of pass duration (dependent variable) as a function of the initial tau value (independent or predictive variable).



**Fig. 4.** Point-by-point tau average band ( $M \pm SD$ ) of the distance motion gap between the 1st receiver and the defender (James, 2004) for all the analyzed trials ( $N = 13$ ).  $X = 0$  marks the instance the 1st receiver receives the ball from the onset of the second phase-of-play, i.e., the beginning of the part of the approach “With the ball”.

### 3.3. Inter and intra-trial tau variability

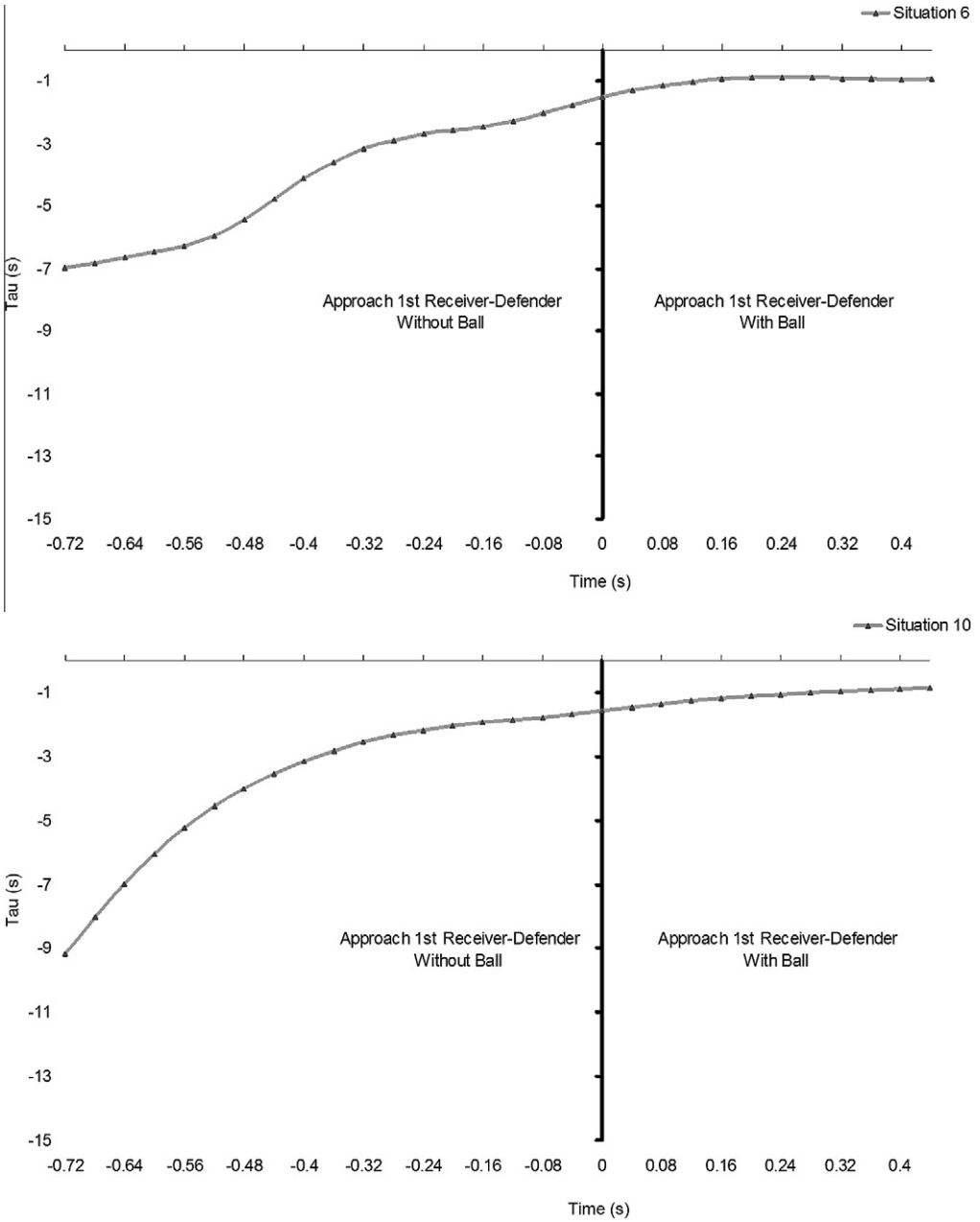
The degree of variability or dispersion in the entire time series tau data (inter-trial variability) in the period up until the first receiver gets the ball (i.e., approach “Without the ball” – left hand side of Fig. 4), and after receiving the ball from the onset of the second phase-of-play (i.e., approach “With the ball” – right hand side of Fig. 4) was accessed by means of the point-by-point variability method. A Wilcoxon signed ranks test revealed that the point-by-point mean tau values computed were significantly greater ( $Z = -2.67, p < .005$ ) for the first period of approach ( $M_{\text{Without the ball}} = -3.56; SD = 3.02$ ) than for the latter ( $M_{\text{With the ball}} = -1.24; SD = .12$ ). Moreover, these periods displayed dissimilar point-by-point mean and standard deviation band’s behavior. Note the higher inter-trial variability during approach “Without the ball”, while a low variability in the approach “With the ball”. A higher standard deviation was found for the approach “Without the ball” data set while a lower standard deviation during the approach “With the ball”. This indicates that these tau data points tend to be much closer to the mean tau in the approach “With the ball”. In the approach “Without the ball”, the higher standard deviation indicates that the tau values during this period are spread out over a larger range of values.

Besides the exhibited inter-trial variability when analyzed individually, in each of the sample situations tau displays a dissimilar behavior before and after the first receiver gets the ball from the onset of the second phase-of-play. Each trial exhibits decreasing values with a more pronounced curve behavior in the first period, but a similar curve shape, and with a smooth continuity over time (see the illustrative trials portrayed in Fig. 5). When compared statistically, the slope was significantly different between the two periods ( $Z = -3.04, p = .001$ ). The slope describing tau as a function of time is likely to be significantly higher during the approach “Without the ball” ( $N = 13; M = 12.12; SD = 11.61$ ), than during the approach “With the ball” ( $N = 13; M = 1.88; SD = 2.24$ ).

## 4. Discussion

This study aimed to obtain further empirical support for the understanding of how information guides movement. More specifically we set out to explore in an actual game of rugby, how





**Fig. 5.** Tau dynamics over the last 18 data points of the period of approach “Without ball” and the first 12 data points of the period of approach “With ball”.  $X = 0$  marks the instance the first receiver receives the ball from the onset of the second phase-of-play, i.e., the beginning of the part of the approach “With ball”. Examples are taken from situation 6 and situation 10.

information, which is directly picked up from the way the motion gap between the defender and the attacker closes, influences the type of pass that is made by the attacker during second phases-of-play.

#### 4.1. Information that influences pass behavior

Potential informational variables, defined in the dynamics of the approach phase between the first receiver and the nearest defender, were analyzed to see whether they influenced the type of pass made by the first receiver. The distance between the attacker and defender was shown to decrease over time indicating a closing motion gap. Although involving different players in different matches and game situations, some pass characteristics, namely pass distance and pass duration, were found to be significantly correlated and linearly related with the initial tau value of the closing distance motion gap. The initial value of the invariant tau specifies how the gap between attacker with the ball (first receiver) and the defender is closing over time at the instant the first receiver gets the ball. This is in line with the key idea of prospective control underlying general tau theory (e.g., Lee & Young, 1985; Montagne, 2005; von Hofsten, 1993). As Grealy, Smith, and Pepping (2007) commented about timing of initiation of the action “it is frequently not critical when a movement starts—just so long as it does not start too late” (p. 122). Likewise, the critical information (for pass possibility perception) might not be perceived at the instant of a given action but prior to that (in this case, in the initial tau of the distance between opposing players). This suggests prospective guidance of movement. The initial tau may be regarded as prospective in the sense that the rate of change of the distance between the players informs the first receiver about the adequacy of their current approach movement in order to perform a pass to a perceived teammate positioned closer or further away from him (corresponding to a short or longer pass). One may assume that with this online guidance, players prospectively perceive which pass is a possible action. Above all, our results may be viewed as demonstrating that it is at the instant the player receives the ball (initial tau) that he perceives whether the time remaining to collide with the defender will allow him to perform that pass. Along these lines, initial tau was therefore found to prospectively guide the behavioral decision about the type of pass. A regression analysis reinforced these findings. The observed strong relationship (accounting for a high percentage of the variance) between an informational variable (initial tau) and a resulting action (pass) supported the hypothesis that perceptual variables embedded in the dynamics of the changing gap between attacker–defender influenced decisional events, such as when and how to pass. More specifically, the regression suggests that the closer the tau value is to zero, that is to say the less time there is until the gap between the players is closed, then the shorter the duration of the pass. In terms of action organization, longer passes will obviously take longer and will only occur when the initial tau value specifies a longer time frame in which the action can take place. Furthermore, if the decision to pass further or shorter was only made at the moment it is observed, one could expect that the time remaining to contact the defender when the attacker (first receiver) passes the ball (i.e., final tau) would be also correlated with the variables associated with the length of pass (duration and distance). However our data did not find this relationship to be significant. This means that when the attacker receives the ball, perceiving the way that gap to the defender is changing may allow him to perceive a future state of that gap and essentially the future action possibility.

Only tau and not any other approach variable, such as the initial distance between the players (attacker–defender) or motion gap duration, was predictive of any pass characteristics. This provides support that instead of making complicated computations and inferences about kinematic measures of the approach *per se*, players are simply picking up relevant information from the dynamics of the gap closure as specified by tau. That is, it emphasizes the perception of relevant information embedded in the dynamics of the sporting context. In other words, as stated by Bastin, Craig, and Montagne (2006) a prospective strategy does not entail the identification in advance of the place or the time of contact. Instead, action-relevant information (i.e., the possibility of a pass longer or shorter before an upcoming collision) is specified in the variable tau that is directly available to be perceived in the interaction between the attacker and the defender. These findings can be seen as being in accordance with the theory of direct perception (Gibson, 1979/1986), which supports the idea that perception occurs in the absence of complex computations of kinematic changes. Given that the parameters that determine the type of pass that the player made were shown to be related to the initial tau values, the perception of the pass affordance is suggested to be related to the perception of this higher order variable. This is in accordance with Delafield-Butt and Schöglers (2007) interpretation of tau and its derivative variables as being relational invariants of a functional organism–environment interaction,

and Turvey's (1992) assertion that affordances more than specific action possibilities are interaction or relation possibilities. Accordingly, our findings suggest that decisional behavior or tactic action is not primarily dependent on processing mechanisms of the visual information picked in the approach. Instead, tau information is invariant information perceived directly in the flow field of players' environment. This excludes the need for processing other dimensions of distance, such as velocity or acceleration of the approaching player, with tau alone being sufficient to guide action. Our hypothesis suggests that the direct perception of the time remaining until contact with the defender might be said to afford the choice of pass (long or short, slow or fast) for the attacking rugby player.

As stated before, one important implication of the general tau theory is prospective control (Pick & Pick, 2007). Although the small number of scenes selected for analysis in the current study means we have to interpret the findings with a certain degree of caution, we have however shown from our data how the initial tau may be influencing subsequent action and may therefore support the notion that this variable specifying time-to-contact of the closing gap between attacker and defender is being used as a perceptual variable to prospectively guide pass decisional behavior. Furthermore these findings are consistent with those of other studies on prospective control of action (Kayed & van der Meer, 2009; Lee, Georgopoulos, Clark, Craig, & Port, 2001; Montagne, 2005). Additionally, our results also agree with studies that show how decisions are influenced by prospective information carried in the perceptual flow (e.g., Craig et al., 2006, 2009) and also how prospective control allows for the control of future events and opportunities for action to achieve intended goals (e.g., Turvey, 1992). The findings are also in agreement with the long-standing empirical evidence of timing of specific actions with specific tau-margin values (e.g., Lee & Reddish, 1981; Lee et al., 1983; Wagner, 1982).

#### 4.2. *Tau inter-trial variability*

The predictive relationship revealed between initial tau and pass distance prompted the exploration of tau variability during the approach phase of the attacking runner. Analysis on inter-trial variability showed that tau evolves in a particular way for each situation, being mainly different between situations in the period of approach without the ball. The inter-trial variability was somehow expected since it includes attacker–defender dyads with different starting conditions. For instance, even for two similar situations in which the players approach each other with the same relative velocity (gap closing at the same rate), if the approach of each situation starts from different interpersonal distances (different gap distances to be closed) the value of tau would be different.

#### 4.3. *Attacker–defender dyad constraints and the detection of pass affordance*

When regarding each situation individually, a qualitative distinction of tau dynamics between periods of approach was observed. This was quantitatively corroborated by the significant differences of the slope of the tau dynamics trend line between each period, for all the analyzed situations. In the overall situations and for both periods of approach, tau value dynamics revealed a closing distance motion gap between attacker–defender, differing however in the way tau changes over time, i.e., the rate at which the gap is closing is significantly higher for the “Without the ball” approach. This difference between periods can be explained by the local constraints that come into being at the moment players are engaged in a duel situation, i.e., the attacker with the ball affords tackling for the defending player. In particular, the local constraints change from a strictly informational coupling between players to a more critically close to a physical contact circumstance. This view may be assumed in light of Passos et al.'s (2008) work which showed that decisional behavior of the dyadic sub-systems of team games is regulated by information fields formed by the embedded contextual constraints (Juarrero, 1999). Moreover, previous studies (Passos, Araújo, Davids, Gouveia, & Serpa, 2006; Passos et al., 2008) on rugby attacker–defender dyads, empirically demonstrated that the dynamics describing these dyads changes, or transits to other organizational states, as the interpersonal distance decreases (Passos et al., 2006). Furthermore, it was demonstrated that within a critical interpersonal distance changes in relative velocity embody changes in the informational field governing this system, converging to a single action solution (Passos et al., 2008).

Consequently, as also suggested in these studies, when entering into the period of approach “With the ball”, players might be entering into a region of self-organized criticality conditioning the dyadic system behavior. During the approach “Without the ball” until the ball is received by the first receiver, the space between this player and the defender closes much faster (as shown by the slope of the trend line during this period). But once the first receiver has the ball (approach “With the ball”), the players enter into a second order relation (duel) where the influence on each other is higher, requiring a greater need to accommodate these new constraints, thus increasing the need for better perceptual attunement to relevant informational variables that will inform decisional behavior. In this way, it may be assumed that players are perceptually exploring the information that evolves over time to detect and use, within the emerging and decaying affordances, the best pass affordance.

The design of the present study had the advantage of allowing for the examination of informational parameters embedded in the unfolding interaction between the players and environment and its relation to the action parameters that determine successful performance (effective passes) in the actual game. This methodology and approach might provide a possible way of assessing increased levels of attunement to relevant information variables such as tau during the unfolding interaction. Its exploration and use may provide an important means of guiding goal-directed action to increase the level of successful performance, as argued by Araújo and colleagues (Araújo & Davids, 2009; Araújo et al., 2005; see also, Huet, Camachon, Fernandez, Jacobs, & Montagne, 2009). However, it is worth noting that we did not aim at investigating the development of this coupling between information and action. This was the reason for having players from the same expertise level (illustrating the highest national level). Nonetheless, according to a review by Montagne (2005), the fact that mainstream literature sustains a qualitatively similar regulation of behavior between levels of expertise, suggests that an information–action coupling is easily attained with practice and is present among different levels of player ability. Therefore, we may assume that the coupling between information (tau) and action (pass) would be also verified with novice players after some practice. However, Montagne highlighted that perceptual attunement, in contrast, requires a large amount of practice and is expressed by the experts by their lower overall variability when compared to novices. Besides, attunement entails the enhancement of the relation between information and movement in a functional way (i.e., continuous goal-directed behavioral adaptations of the current relationship between the individual and the environment by the perception of the unfolding invariants). Hence, we may hypothesize that the previously mentioned perceptual attunement to invariants (in this case, the tau information) could be lower and that this could be demonstrated, for instance, in a more variable and less correlated relationship between the tau variables of the approach and pass related ones. Besides, as some authors have empirically demonstrated information is scaled to the action capabilities of the perceiver/actor (for reviews see Fajen et al., 2009; Montagne, 2005), so we may assume that different levels of expertise will correspond to different relations between perceptual variables and action variables.

Pinder, Renshaw, and Davids (2009) recently claimed that to attune perception to invariants, these specifying variables must be available to the actor, something that is not often assured in more abstract experimental set-ups. In the same way, Bootsma and van Wieringen (1990) in their study investigating the perceptual guidance of an attacking forehand drive in table tennis, stated that “experiments in which subjects operate under real-life conditions can be logically expected to render a more thorough insight into the way behavior is coordinated with events in the environment” (p. 22). Therefore in our study, involving the observation and analysis of rugby players while performing in an actual game that incorporates realistic changing dynamics of the player–environment system gives a useful insight into the understanding of the coupling between perception and action that express decisions.

Since information is viewed as having a lawful relation with action, Araújo et al. (2006) emphasized the importance of identifying the informational variables in order to understand the control laws and how they shape decisions expressed in the course of action, i.e., transitions in the player's course of action. The present study was designed to further this area of research and showed how the variables available in the interaction between players and the environment in an actual game significantly correlated with the type of pass that emerged. This line of work should be considered for further research and/or practical applications in the construction of representative designs either in research (in the

design of experimental tasks), or practice (to define practice task constraints) to study/develop the coupling of perception and action.

Future research will engage a deeper analysis of the evolving performance dynamics of each situation and the inclusion of other potential informational variables in order to better understand this phenomenon. It would be of particular interest that further studies include not only the gap between first receiver and the nearest defender, but take also into account the gap between the second receiver and the correspondent nearest defender, as well as the gap between both attackers in order to assess the coordination in the tau guidance of behavior between these players (tau-couplings). In summary, this study may be regarded as providing evidence that action is anticipatory and guided towards future states. In this study we showed how the variable tau is being used as an informational variable that pushes or constrains rugby pass decisional behavior.

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