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THE LEVEL OF INFORMATIONAL DEPENDENCE BETWEEN GAZE BEHAVIORS IN DECISION-MAKING ON SHOOTING THROUGHOUT A FUTSAL GAME

RAVEN INFORMACIJSKE ODVISNOSTI MED VEDENJEM POGLEDA PRI ODLOČANJU O STRELJANJU V IGRI FUTSALA

ABSTRACT

Purpose: This study investigated whether gaze fixation behaviors during shooting situations influence subsequent visual behaviors throughout a futsal game. *Methods:* A total of thirty shots from seven futsal players who wore an unobtrusive eye tracking device during matches of futsal were analyzed using the Kinovea software. The visual information were analyzed from the moment a teammate passed the ball to the shooter (initial moment) until the moment the shot was performed (final moment). The analyses employed normalized mutual information (NMI). *Results:* The results showed that the NMI values were close to zero, suggesting minimal dependence between gaze fixation behaviors in consecutive shots. *Discussion and Conclusions*: These findings indicate significant variability in players' gaze fixation behaviors during shooting situations, which may reflect their adaptive responses to the game's dynamic conditions. The identification of multiple gaze fixation patterns among players suggests that different strategies may be employed to optimize performance in response to varying game contexts, offering new insights into the role of visual information in futsal.

Keywords: eye tracking, adaptive behaviors, normalized mutual information, team sports, futsal

IZVLEČEK

Namen: Ta študija je preučevala ali vedenje fiksiranja pogleda med situacijami streljanja vpliva na poznejše vizualno vedenje skozi igro futsala. *Metode*: S programsko opremo Kinovea je bilo analiziranih skupno trideset strelov sedmih igralcev futsala, ki so med tekmami futsala nosili nemotečo napravo za sledenje očem. Vizualne informacije so bile analizirane od trenutka, ko je soigralec podal žogo strelcu (začetni trenutek) do trenutka, ko je bil izveden udarec (končni trenutek). Analize so uporabile normalizirano medsebojno informacijo (NMI). *Rezultati*: Rezultati so pokazali, da so bile vrednosti NMI blizu nič, kar kaže na minimalno odvisnost med vedenjem fiksiranja pogleda v zaporednih posnetkih. *Razprava in zaključki*: Te ugotovitve kažejo na veliko variabilnost v vedenju igralcev pri fiksiranju pogleda med situacijami streljanja, kar lahko odraža njihove prilagodljive odzive na dinamične pogoje igre. Identifikacija več vzorcev fiksiranja pogleda med igralci nakazuje, da se lahko uporabijo različne strategije za optimizacijo uspešnosti kot odgovor na različne kontekste igre, kar ponuja nov vpogled v vlogo vizualnih informacij v futsalu.

Ključne besede: sledenje očem, prilagodljiva vedenja, normalizirane medsebojne informacije, ekipni športi, futsal

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INTRODUCTION

Over the past few decades, players' decision-making ability has increasingly been considered as *sine qua non* for success in team sport (Araújo et al., 2006; Causer & Williams, 2013; Hastie, 2001; Raab et al., 2019; Ripoll, 1994; Tenenbaum et al., 1993; Williams & Jackson, 2019). This is because team sport match unfold as a process of continuous emergence of situations involving several possibilities for action. For example, when receiving the ball, a futsal player can make the decision to perform a pass, a dribble, a shot or drive. Still, each of these decisions comprises several alternatives such as how, where, and/or when to perform it. In such sports, players simultaneously make decisions to cooperate with each other by performing motor skills with and without the ball to, as a team, oppose the other team (Corrêa et al., 2012a; Davids et al., 2005; McGarry, 2009). Considering the natural dependence between context and actions for success, the ongoing interactions in team sports must be considered as an informational source for decision-making in team sports.

Based on this, researchers have developed a body of studies to understand how information on players' interactions (i.e., interpersonal coordination) constrains players' decision-makings (Denardi et al., 2016; Passos et al., 2013, 2016; Vilar et al., 2013). The main assumption here is that players make decision based on perceived properties of interpersonal coordination (e.g., area, angle, distance, and velocity). For instance, regarding the team sport of futsal studies have pointed out that players make decision based on (i) angles involving the passer, receiver and their markers for passing direction and velocity (Corrêa et al., 2012a, 2014a; Silva et al., 2017); (ii) distance between the passer and the defenders, and between the two closest defenders for passing moment (Corrêa et al., 2020a; Travassos et al., 2012a); (iii) distance between the marker and the passer (pressure) and the line of the ball (Travassos et al., 2012a) as well as on the changing the defensive area for ball interception (Corrêa et al., 2014b; Travassos et al., 2011, 2012b); (iv) variability of the passing and shooting angles for dribbling (Corrêa et al., 2016); (v) spatiotemporal information about the closest defender and the goalkeeper for shooting (Vilar et al., 2012a); and (vi) distance to the goal and ball line to anticipate the shot (Vilar et al., 2012b).

These findings have provided important insights on how interpersonal coordination information constrains decision-making in futsal. Following this line of thinking, further studies investigated how futsal players behave visually with such informational variables in the shooting situation (Corrêa et al., 2020b; Oliveira et al., 2023). These studies have demonstrated that (i) the longer the time of ball possession, the greater the variability in visual search because futsal players look for an optimal value of angular interpersonal coordination (Corrêa et al., 2020b); (ii) futsal players vary their gazes among the nearest defender, goalkeeper, court floor, and ball, the latter two being used as an anchor point and postural and accuracy controls, respectively (Oliveira et al., 2023).

Despite the cumulative knowledge gathered through these studies, it is important to note that the nature of a team sports match must be further incorporated in the analyses and interpretation of decision-making studies. These previous studies were analyzed by grouping shots (e.g., averaging) independent of their temporal aspects. This disregards the fact that the shots occur within a sequence of events that comprise the futsal game. However, the game unfolds as a non-autonomous coupled dynamic system; that is, a system that has time-dependent changes depending on the status of both teams operating (e.g., while one attacks, the other defends; further attacks do not lead to the same responses) (Corrêa et al., 2012b). Furthermore, the fact that teams influence each other, but without absolute correspondence between their actions, makes the changes a non-linear process (Clavijo et al., 2022).

Therefore, the current study sought to extend previous findings by exploring how futsal players use the visual information for decision-making on shootings throughout the game. Our question was given the game is a dynamic system, would previous gaze behaviors in shooting situations influence subsequent gaze behaviors throughout the game? Would there be patterns of visual information used in shooting situations throughout the game? To answer these questions, data from gaze behavior (fixation and its duration) of shooting situations over futsal games were analyzed complementarily by methods of mutual information (e.g., Williams, 1997) and clustering (e.g., Schöllhorn et al., 2013). While the first allows accessing the amount of information that one variable contains about another in different points over time, the second allows the use of similarity (or distance) measures to form clusters between the visual behavior patterns throughout the game.

METHODS

Participants

They were seven amateur players with normal visual acuity (average age of 18.85 ± 1.66 years), who voluntarily played competitive matches of futsal wearing an unobtrusive eye tracking device. The volunteers were also identified by the coach as those players with the greatest tendency to perform shots. Participation required the volunteers' written consent, and the experimental protocol was given ethical approval by the local Institutional Review Board.

Procedures

An Eye Tracking System (TOBII PRO, Danderyd, Sweden) was utilized by one player from each team in each half of the game. This apparatus allows capturing the corneal and pupil behavior, thereby enabling inferences about gaze fixation and its duration (Duchowski, 2007; Holmqvist & Anderson, 2017). The visual information from the TOBII PRO eye-tracking videos were analyzed through the KINOVEA software 8.27 (http://www.kinovea.org), from the moment a teammate passed the ball to the shooter (initial moment) until the moment the shot was performed (final moment). It ranged from 0.36 to 5.28 seconds. The inter-rater reliability was verified through re-analyze five minutes of the game by another researcher (r = 0.94, $p < 0.01$).

Data analyses

30 shots were collected. However, one player performed no shots, two players performed only one shot, and one player performed only two shots. Therefore, to meet the objective of the present study, the analyzed sample comprised data from 26 shots performed by 3 players.

For the first analysis, data were analyzed using the mutual information method (see Williams, 1997 for a tutorial). This is a measure that quantifies the extent to which one variable reduces the uncertainty (a measure of information in Information Theory terms). It can also be employed to assess the information that a given point in time "carries" to another (Cover & Thomas, 1991; Williams, 1997). This measure ranges from zero, indicating the absence of a relationship between two time points, to infinite (only depending on the total entropy of the system).

To conduct this analysis, the gaze fixation durations over each shooting were divided into quartiles (Altman & Bland, 1994) as follows: player A [first quartile (Q1), from 40 to 80 ms; second quartile (Q2), from 81 to 200 ms; third quartile (Q3), from 202 to 420 ms; fourth quartile (Q4), from 425 and 3160 ms]; player B [Q1, from 40 to 70 ms; Q2, from 72 to 160 ms; Q3, from 170 to 450 ms; Q4, from 460 to 1600 ms]; player C [Q1, from 40 to 130 ms; Q2 from 135 to 300 ms; Q3, from 303 to 770 ms; Q4 from 780 to 2560 ms]. The data were organized based on transition probabilities within each shot. For instance, the interest area of gaze fixation and its quartile of time were combined into a single variable. For instance, during a shot, a player may have focused on the ball with a fixation time in quartile 3 (Q3), on the ground with a fixation time in quartile 2 (Q2), on the opposing goalkeeper with a fixation time in quartile 1 (Q1), and again on the ball with a fixation time in quartile 4 (Q4). These data represented the following gaze behaviors: transition probability of the state “ball-quartile3” for the state “ground-quartile2” and transition probability of the state “opposing goalkeeper-quartile1” for the state “ball-quartile4”, respectively. A mathematical entropy function was used to quantify the randomness associated with the probabilities of a player select the “ball-quartile3” option, and then the “ground-quartile2”, “opposing goalkeeper-quartile3”, and finally the “ball-quartile4” options (for instance, see Lai et al., 2005, 2008).Thus, this meant that the first state, for example, "ball-quartile", was considered the variable X in the equations, and the second state, "teammate-quartile3", was considered the variable Y in the equations. This logic was applied throughout all gaze fixations of all kicks that resulted in time terms $t + t1$. The marginal probabilities were then employed to calculate the entropies of each variable I (X) and II (Y) using Shannon's entropy formula (Shannon & Weaver, 1949) (equations 1 and 2).

Equation 1:

$$H_X = -\sum_{i=1}^{N_s} P(x_i) \log_2 P(x_i)$$

where H_X is the entropy of the random variable x. It represents the average amount of information (or uncertainty) generated by each value of x; N_s is the total number of possible states or distinct values that x can assume. $\sum_{i=1}^{N_s}$ is the summation that iterates over all N_s possible values of the variable x; $P(x_i)$ is the probability of the i-th value x_i of the random variable x; $\log_2 P(x_i)$ is the logarithm, base 2, of the probability $P(x_i)$. The use of a logarithm with base 2 measures the amount of information in bits; the negative sign (−) ensures that entropy is always positive, since $P(x_i)\log_2 P(x_i)$ is negative when $P(x_i)$ lies in the interval (0,1).

Equation 2:

$$H_Y = -\sum_{j=1}^{N_s} P(y_j) \log_2 P(y_j)$$

where H_y is the entropy of the random variable x. It represents the average amount of information (or uncertainty) generated by each value of y; N_s is the total number of possible states or distinct values that x can assume; $\sum_{i=1}^{N_s}$ is the summation that iterates over all N_s

possible values of the variable *x*; $P(y_i)$ is the probability of the *i*-th value y_i of the random variable *y*; $\log_2 P(y_i)$ is the logarithm, base 2, of the probability $P(y_i)$. The use of a logarithm with base 2 measures the amount of information in bits, the negative sign (−) ensures that entropy is always positive, since $P(y_i)\log_2 P(y_i)$ is negative when $P(y_i)$ lies in the interval (0,1).

Subsequently, the joint probability matrix, represented by $P(x_i, y_j)$, was calculated to demonstrate the influence of the relationship between variables on the occurrence probabilities of different event combinations. Additionally, the conditional probability matrix, represented by $P(y_j \mid x_i)$, was calculated, providing the probabilities of an event occurring given another event. The conditional entropy of variable Y given the specific value or event of variable X, or $H_{Y \mid X}$, was calculated. The mutual information was then determined according to equations 3 and 4.

Equation 3:

$$H_{Y|X} = -\sum_{i=1}^{N_s}\sum_{j=1}^{N_s} P(x_i)P(y_i|x_i)\log_2 P(y_j|x_i)$$

where $H_{y|x}$ is the conditional entropy of *y* given *x*. It represents the average amount of uncertainty (or information) about the variable *y* when the variable *x* is known; $P(y_j|x_i)$ is the conditional probability of y_j given x_i. In other words, it is the probability that $y = y_j$, given that $X = x_i$. $\sum_{i=1}^{N_s}\sum_{j=1}^{N_s}$. These are the two summations that iterate over the possible values of *x* and *y*. The first summation iterates over all possible values of *x* (from $i = 1$ to N_s, where N_s is the total number of possible states or values that *X* can assume). The second summation iterates over all possible values of *y* (from $j = 1$ to N_s). $\log_2 P(y_j|x_i)$: The logarithm with base 2 of the conditional probability $P(y_j|x_i)$. This logarithm measures the amount of information (in bits) associated with the probability $P(y_j|x_i)$. The negative sign (−) at the beginning of the equation ensures that the entropy is always positive.

Equation 4:

$$I_{Y;X} = H_Y - H_{Y|X}.$$

where $I_{y|x}$ is the mutual information between *y* and *x*. It quantifies the amount of information that the variable *x* provides about *y*; H_Y is the Entropy of *y*. It represents the amount of uncertainty (or information) about the variable *y* without any additional knowledge of *x*; $H_{y|x}$ is the conditional entropy of y given x. It represents the amount of uncertainty about y when the variable x is known.

Given the upper limit of mutual information is contingent on the entropy of the variable, comparisons between samples are rendered challenging (Fedorowich et al., 2015; Johansen et al., 2013; Madeleine et al., 2011). To address this, a normalized version of mutual information (NMI) was implemented and defined as follows:

Equation 5:

$$NMI = \frac{Iy;x}{H(x)*H(\gamma)}$$

where NMI is the Normalized Mutual Information. This is a normalized version of the mutual information between two variables y and x; $I_{y;x}$ is the Mutual Information between y and x. This measures the amount of information that x provides about y (or vice versa); H(x) is Entropy of x; and H(y) is Entropy of Y.

This normalization resulted in NMI values ranging from 0 to 1. The value of 0 meant no dependence between variables. On the other hand, the value of 1 indicated complete dependence among them (Johansen et al., 2013; Kawczyński et al., 2015; Madeleine et al., 2011). All mutual information analyses were conducted using R software version 4.2.0.

RESULTS

Regarding the descriptive trends of visual behaviors, the results showed that the main areas of interest for gaze fixation were the goalkeeper, a teammate, an opponent, the court floor, and the ball. It was found that, while players A and C fixed their gaze on the ball, the opponent, and the court floor, player B, in addition to these items, fixed his gaze on the opposing goalkeeper and his teammate. Table 1 shows the ball was the item most focused on during the shots, especially those performed by players A and B. It can also be observed that the court floor was the focus of fixations, but in a smaller amount than the ball. It is interesting to note that player B's shots were those with the greatest amount of fixation focuses. In relation to the gaze fixation time, Table 1 shows the ball was the item with the longest fixation time. Some highlights can be observed in shots 2 and 3 by player C and shot 4 by player B, in which the court floor had the longest fixation time.

Table 1. Relative frequency (%) and average duration (ms) of gaze fixation on each interest area (goalkeeper, teammate, opponent, court floor, and ball).

	Goalkeeper		Teammate		Opponent		Court floor		Ball	
Player	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)
A	-	-	-	-	0,52	40	8,9	170	90,58	461,33
B	2,07	120	3,63	96	11,05	320	9,15	163,08	74,09	536,25
C	-	-	-	-	0,58	80	26,51	283,08	72,91	843,33

The values of NMI analysis are presented in the Figure 1. It shows that Players A, B, and C exhibited 0.26, 0.13, and 0.20 of NMI.

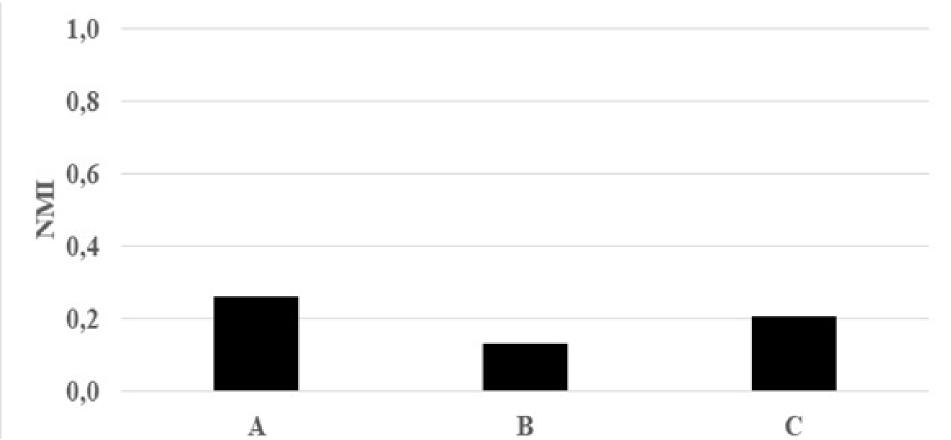

Figure 1. Normalized mutual information (NMI) for Players A, B, and C’s gaze behaviors.

DISCUSSION

This study investigated whether previous gaze behaviors in shooting situations would influence subsequent gaze behaviors throughout the game. The main results indicated that normalized mutual information obtained values close to zero.

Although normalized mutual information has been utilized in many studies in recent years (e.g., Fedorowich et al., 2015; Johansen et al., 2013; Kawczyński et al., 2015; Kristiansen et al., 2023; Lai et al., 2008; Madeleine et al., 2011, 2016; Murakami & Yamada, 2022), none of them investigated the shooting in futsal. Regarding this motor skill, our results indicated that there was almost no dependence from the previous gaze behaviors on the subsequent ones, that is, what and how players focused on at time *x* reflected very little on what they focused on at time *x* + 1 (Williams, 1997).

This derisory informational dependence can be explained by considering the futsal teams as hierarchical adaptive systems (e.g. see Corrêa et al. 2021). Hierarchical systems like futsal can comprise two main levels: (1) the inferior one is known as microstructure; it refers to the players individual behaviors; and (2) the superior level, called macrostructure, is the result of the interaction between players: the team. Generally, in team sports macrostructure is defined by the tactics adopted by the team. For instance, a given futsal team may decide to play in a diamond formation (1-2-1) (i.e., one player in the defense, two players laterally in midfield, and one attacking player up front). The hierarchy here consists of macrostructure defining the roles of the players for the emergence of the diamond. However, the individual behaviors (e.g., what and how they will do to perform their roles) will be constrained by the game circumstances (e.g., the actions of the opponents). This is why the way that players interact is less variable than their individual behaviors. That is, as a hierarchical systems the futsal teams show regularity and spatiotemporal pattern at the macroscopic level, and irregularity in behaviors at the microscopic level (Clavijo et al., 2022; Reis & Corrêa, 2021).

Furthermore, as previously described, the game of futsal unfolds because of the simultaneous work of opposition in which one team acts to take advantage of the other. For example, while the attacking team acts to generate uncertainty for the defending team, the latter works to obtain information from the opponent (to reduce uncertainty) and use it to recover the ball possession. This process of reducing/increasing uncertainty may generate different degrees of perturbation between the teams. From a hierarchical systems point of view, in this case the teams may deal with perturbation by adapting themselves in two main ways. First, the team might alter their microstructure – modify parameters of one or another player (e.g., running faster or slower, or playing more wide or tight). In this case, there is maintenance of macrostructure because players can run faster or slower with the team playing in a diamond formation. It is this type of adaptation that characterizes the regularity of a team throughout the game (McGarry, 2013; McGarry & Franks, 1996; McGarry et al., 1999, 2002). Second, reorganizing their macrostructure by adopting a new organization (Tani et al., 2014). For example, faced with a perturbation, a team could change the pattern of interaction between players so that the team changes the playing system from a diamond to a square (i.e., from 1-2-1 to 2-2) (Corrêa et al., 2012b).

Based on the foregoing, the weak dependence between the gaze fixation behaviors in the shots throughout the game may have occurred because the shooting situations demanded different macrostructures. To put it another way, the perturbations generated by the defensive team throughout the game may have required a new organization of the attack for the performance of each shot. For this reason, there was a very weak relationship between gaze behaviors.

Obviously, this does not mean that the whole game developed based on the emergence of novelty/creativity, as we only analyzed the shooting. Furthermore, relatively few occurrences (probabilities) of the gaze fixation focus were noted during shots, with three occurrences for two players and five for one player. In them, the occurrence of ball fixation was greater than other areas of interest, which may indicate that this variable has a dominant influence or that other variables do not have much influence on it. This may also explain the weak dependence found. In other words, most of the data were related to the ball, and there was little variation or influence from other variables, therefore, the observation of the ball brought very little additional information about the other variables (Kvålseth, 2017).

The fact that the ball was the most focused item and had the longest fixation duration can be due its central role in the game and in shootings (Jerome et al., 2024, Oliveira, 2023). Players direct their gaze to the ball to ensure accuracy in its contact with the foot (Dörge et al., 2002; Shan & Zhang, 2011). In addition, focusing on the ball during the kick makes it easier for players to regulate the postural and biomechanical adjustments necessary for effective kick performance (Dörge et al., 2002; Shan & Shang, 2011). Another explanation is that the gaze fixation on the ball may have been used as a pivot or visual anchor. Visual anchoring refers to the fixation of the gaze on a specific point on the court so that constant saccadic changes are not necessary to monitor the positioning of other players (Vater et al., 2019). On the other hand, the visual pivot involves the visual exploration of the environment around this anchor point, allowing the player to select the next fixation on a peripheral information source (Vater et al., 2019). Therefore, the gaze fixation on the ball during shots may have been functional for players to simultaneously monitor different sources of information (Oliveira et al., 2023; Ryu et al., 2013).

CONCLUSION

In summary, the results of this study allow us to conclude there was little informational dependence between gaze behavior patterns throughout the game because they occur in a nonsequential order of structural and parametric adaptations. One could argue that the small number of players and shots could be considered a limitation of this study. However, it is important to consider that this reflects the nature of the game. For example, there is no guarantee that a player will perform many shots in over the game. Our study provides insights for new considerations on gaze behavior in sport contexts, going beyond the "aggregate" behavior (averages) of previous studies. Despite the advances and limitations, as part of the scientific enterprise these findings need to be replicated, including in relation to other futsal motor skills, in order to guarantee them the consistency necessary for generalization and transformation into knowledge for the practice of futsal.

Declaration of Conflicting Interests

No potential conflict of interest was reported by the authors.

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