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The association between visual exploration and passing performance in high-level U13 and U23 football players

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ABSTRACT

Purpose: The visual exploratory actions (i.e., scanning head movements) used by football players to perceive their surrounding environment have recently gained interest. While this has resulted in important findings relating to visual exploration during natural match-play, often the study designs lacked the experimental control of laboratory-based experimental settings. We aimed to investigate whether visual exploratory action is associated with passing performance for high-level U13 and U23 players in a controlled skill assessment setting.

Methods: Fourteen U13 and 13 U23 football players from a Bundesliga club completed a standardised 32-trial sequence in the Footbonaut. Exploratory head movements were recorded with a head-worn inertial sensor, from which the count, frequency and excursion of head movements were extracted before and during ball possession. Ball reception and disposal were coded for each trial, and performance was operationalised as the time taken to complete each trial.

Results: Across all players, visual exploratory action was associated with passing performance. The variables that best explained faster performance were 1) a higher number of head turns before receiving the ball, 2) a lower number of head turns when in possession of the ball, and 3) being an U23 player. However, different combinations of variables explained performance for U13 and U23 players.

Conclusion: The findings demonstrate the value of scanning before receiving the ball to prospectively control passing actions in the Footbonaut. Future research should investigate the shared and contrasting characteristics of scanning actions, as they are observed by players in skill assessment tasks such as the Footbonaut, during training and during match-play.

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Scanning; performance; decision-making; soccer; situation awareness; Footbonaut

Introduction

Football (Association Football) performance is determined by the interaction between technical, tactical, physical and psychological components of play (Hughes et al. 2012; Brink and Lemmink 2018; Lovell et al. 2018). While each of these components of play has been investigated, technical skills such as passing ability have received significant attention, particularly from performance analysis (Liu et al. 2015, 2016; Rein et al. 2017; Varley et al. 2017; Loxston et al. 2019) and talent identification (Vaeyens et al. 2006; Bennett et al. 2017; Sarmento et al. 2018) perspectives. Further, coaches consider technical attributes to be highly important across various playing positions (Roberts et al. 2019), whilst attributes related to an athlete's perceptual-motor abilities, such as perception of affordances, calibration and attunement (Dicks et al. 2017; van Andel et al. 2017; Pacheco et al. 2019), have received considerably less attention. Importantly, the perceptual-motor abilities of players are intimately linked with the performance of technical actions (McGuckian et al. 2018b; Dunton et al. 2019). Given the above, when investigating the successful performance of technical actions, related perceptual-motor factors should also be considered.

One perceptual-motor factor that has been shown to be related to successful passing performance is the visual exploratory actions (VEA) which precede gaining possession of the ball (Jordet 2005; McGuckian et al. 2018c). These VEA, characterised by turning of the head about the longitudinal axis, provide players with information about their surrounding environment. Research has defined a range of VEA variables in attempts to understand different qualities of exploratory movement and its relation to performance. Typically, there are three main variables that are extracted. The count of head turns represents the total number of head movements completed in a predetermined time, head turn frequency (HTF) represents the number of head movements per second, and head turn excursion (HTE) represents the total size (in degrees) of head movements per second (Chalkley et al. 2018; McGuckian et al. 2018b, 2019). An important aspect of VEA is whether a player is in possession of the ball or not, as VEA *before* ball possession (i.e., action orientation) may relate to prospective regulation of movement with the ball differently than VEA *during* ball possession (i.e., action specification, see van Andel et al. 2019). Therefore, research has also typically quantified the count, HTF and HTE separately for the time before ball possession (termed the exploration phase) and while a player is in ball possession (termed the possession phase) (McGuckian et al. 2019, 2020). The count and HTF of VEA give an indication of *how often* a player is changing their visual orientation to

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perceive their environment, while the HTE gives an indication of *how much* of the environment a player is exploring (Freedman 2008; Chalkley et al. 2018; McGuckian et al. 2018b).

The information gained from VEA has been shown to be used to prospectively guide actions leading up to and during possession of the ball, with more extensive VEA (i.e., higher count, HTF or HTE) being related to higher pass success (Jordet et al. 2013), higher likelihood of turning with the ball and playing attacking passes (Eldridge et al. 2013; McGuckian et al. 2018b), and quicker passing responses (McGuckian et al. 2019). However, constraining factors, such as playing role, pitch position and phase of play have been shown to influence VEA (McGuckian et al. 2020), which demonstrates the complex relationship between VEA and performance. Still, the value of VEA for performance is clear. What is more, highly experienced football coaches perceive VEA to be a particularly important skill, and they are more likely to prioritise the development of VEA in their training programs (Pulling et al. 2018).

The Footbonaut (CGoal GmbH, Berlin, Germany) is a skill assessment and training tool that consists of an artificial turf surface surrounded by eight ball dispensing machines and 64 square target gates. The machine can be custom programmed to dispense balls at various speeds, at various angles and with various ball spin, and the target gates can be custom timed to indicate the location that balls should be kicked to. Performance is automatically measured according to the accuracy and speed of passing. The test–retest reliability and discriminant validity of the Footbonaut have recently been demonstrated in high-level football players aged U12 to U23 (Beavan et al. 2019a). The Footbonaut demonstrated acceptable test–retest reliability across all age groups and was able to discriminate between younger (U12-U14) and older (U15-U23) players. Due to the vast combinations of ball dispensing and target locations, the Footbonaut has been used as an assessment tool for technical control, passing and shooting ability in an unpredictable and 360-degree environment. Despite being able to discriminate between younger and older players, the factors that contribute to these differences in perceptual-motor performance in the Footbonaut are unclear. In order to better understand perceptual and passing performance in the Footbonaut, and to facilitate transfer of perceptual and passing performance from skill assessment (the Footbonaut) to training and match-play scenarios, there is a need to quantify the perceptual aspects that relate to improved passing performance in the Footbonaut.

The current study aimed to address a gap in the current literature by investigating the relative influence of VEA variables on passing performance in the Footbonaut. High-level U13 and U23 football players were recruited in order to test i) the difference in VEA used by the two age groups and ii) the relative role of VEA on passing performance for players at different developmental stages. Given the influence of playing position on VEA during match-play (McGuckian et al. 2020), playing position was also investigated as a factor of interest. Following previous research (Eldridge et al. 2013; Jordet et al. 2013; McGuckian et al. 2018b, 2019), it was expected that older players would complete passes more quickly and use more extensive VEA before receiving possession of the ball than younger players and that more extensive VEA before receiving the ball would contribute to better performance on the football passing task.

Materials and methods

Participants

Twenty-seven male football players representing a high-level club in the top German league (i.e., Bundesliga) participated in this study (Beavan et al. 2019b). The sample consisted of two cohorts: U13 (n = 14, 1.56 ± 0.07 m, 45.9 ± 6.8 kg, 7.8 ± 1.7 years of experience playing football) and U23 (n = 13, 1.84 ± 0.08 m, 76.1 ± 8.0 kg, 12.7 ± 3.5 years of experience playing football). Prior to the commencement of this study, informed consent for all participants was received, and the Institutional Ethics Committee approved this study.

Procedure

Data collection followed a standardised testing procedure for all participants. All participants were familiar with using the Footbonaut prior to completing the testing procedure. Head movement data were collected with a 9-DOF Inertial Measurement Unit (IMU; IMeasureU Blue Thunder, Vicon, Oxford, UK) at 500 Hz. Following similar investigations (McGuckian et al. 2018b, 2019, 2020), the IMU was mounted in an elastic headband, and worn such that the device sat at the external occipital protuberance. A video camera (GoPro, San Mateo, USA) was mounted to the Footbonaut at a height of 1.5 m and sessions were recorded at 50 Hz.

Upon arriving at the facility, participants were briefed on the Footbonaut testing procedure. Participants were instructed to 'complete the testing procedure as fast and accurately as possible'. The testing procedure consisted of a standardised combination of 32 trials as described by (Beavan et al. 2019a). To begin each trial, a ball dispenser gate lit up red as a visual signal accompanied by an auditory signal to indicate where the ball would be dispensed from. This was immediately followed by a target gate lighting up green as a visual signal accompanied by an auditory signal to indicate where the participant should pass the ball to. The ball was dispensed at 50 km/h. After the participant had passed the ball through the target, the next trial would start. The dispensing order, speed of balls and delay between signal and ball dispensing were consistent for all participants.

Data analysis

Following the completion of testing sessions, IMU and video data were downloaded for analysis. A summary of the variables used for analysis is presented in Table 1. SportsCode v11.2.15 (Hudl, Lincoln, USA) was used to determine exploration and possession phases for each trial. The exploration phase was defined as the period from the red visual signal (i.e., trial start) until the participants made the first contact with the ball. The possession phase was defined as the period between first contact with the ball and final contact with the ball. Performance for each trial was assessed using the total time that was taken to complete the trial. This value is calculated automatically by the Footbonaut and was defined as the duration between the ball being dispensed and the ball entering the target gate. Therefore, performance was assessed by the total time taken to receive, control and pass the ball to the target.

Table 1. Operational definition of each variable used in analysis.

Variable	Definition
Head turn count: exploration phase (HTC:E)	The total number of head turns during the exploration phase.
Head turn count: possession phase (HTC:P)	The total number of head turns during the possession phase.
Head turn count: possession phase polynomial (HTC:P^2)	A polynomial of HTC:P. See Figure 1 for a comparison, and statistical analysis for more details.
Head turn excursion: exploration phase (HTE:E)	The total size (in degrees) of head turns during the exploration phase.
Head turn excursion: possession phase (HTE:P)	The total size (in degrees) of head turns during the possession phase.
Head turn frequency (HTF)	The total number of head turns divided by the total duration of the trial. Presented as head turns/second
Head turn excursion (HTE)	The total size of head turns divided by the total duration of the trial. Presented as degrees/second.
Playing position	The preferred playing position of the players, either goalkeeper, defender, midfielder or forward.
Age group	The age group of the players, either U13 or U23.

Head turns were automatically detected and analysed from the IMU data using a previously validated custom-made algorithm (Chalkley et al. 2018). A head turn was defined as a distinct movement of the head about the longitudinal axis that resulted in an angular velocity exceeding 125 degrees/second (Chalkley et al. 2018; McGuckian et al. 2018a, 2018b, 2019, 2020). Head turn excursion was defined as the total angular distance of each head turn event.

Statistical analysis

Following previous research (McGuckian et al. 2019), the current study aimed to understand what exploratory variables influenced the speed of completion of a *successful* pass, which, in the Footbonaut, was defined as a pass that ended in the target gate. Speed and accuracy of trials were highly correlated (−0.48). In total, 77.1% of the trials were successful across the whole dataset, therefore leaving the working sample to 651 trials (U13 n = 310, U23 n = 341) from the original 864 trials.

To investigate which variables (as listed in Table 1) were most associated with time to completion of each trial, a best subset regression model was used (Atkinson & Nevill, 2001). The best subset model ran a linear model for every combination of variables to identify what combination of variables was best associated with time to completion of each trial. Using RStudio (Version 1.1.419), the best subset selection model demonstrated how many variables were optimal to produce the best outcome, and which factors made up that combination. The best subset models were determined based on four criteria: i) the coefficient of determination (R^2); ii) the adjusted coefficient of determination (adjusted R^2); iii) the Bayesian Information Criterion (BIC); and iv) the estimate of prediction of errors (Cp). Upon visual inspection of scatterplots of the relationship between the number of head turns in the exploration and possession phases and time to completion, it appeared that a polynomial model could improve the model fit. Therefore, both HTC:E and HTC:P were transformed into a second-order polynomial model and compared against the linear models (Figure 1). HTC:P^2 significantly

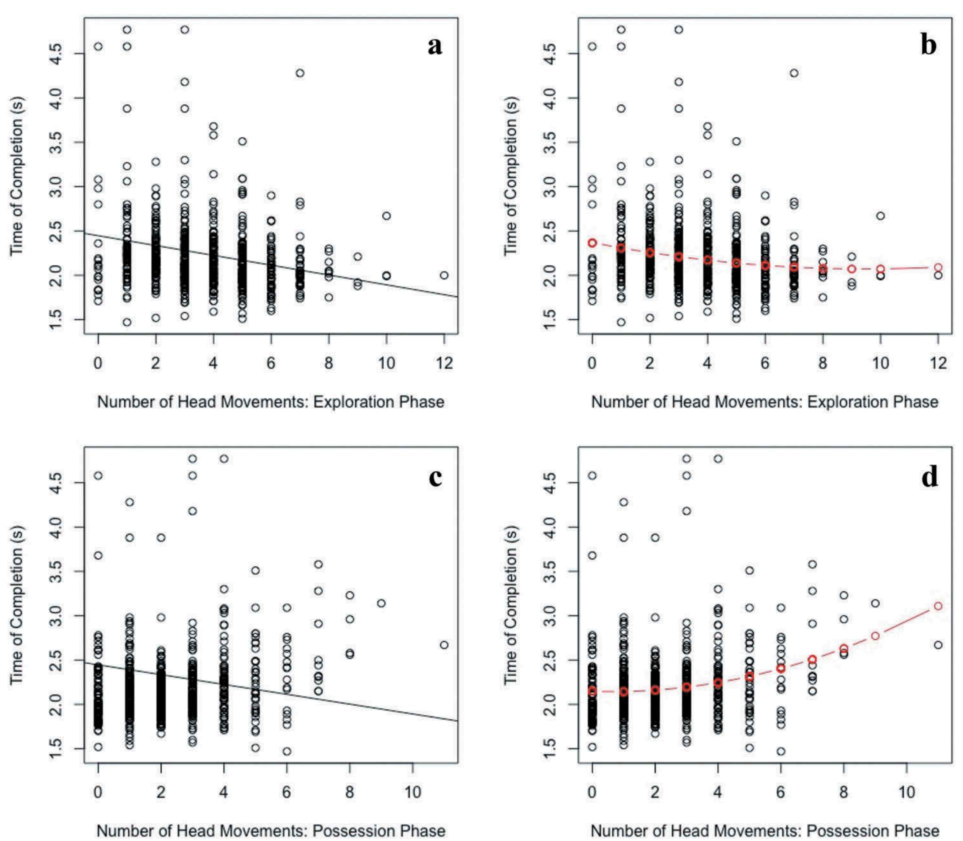

Figure 1. Observable scatterplots of relationship between number of head movements and time of completion in the exploration phase (A & B) and possession phase (C & D) with linear and exponential models used to investigate best fit.

improved the model fit (0.005), whereas HTC:E^2 did not sufficiently improve the model fit (0.09). Therefore, HTC:P^2 was retained in the analysis alongside HTC:P. Collectively, both linear and non-linear regression models analysed the effect of various head movement variables on the time to complete a successful pass in the Footbonaut. The significance level was set at $p < 0.05$, and an estimate precision was provided using Wald-based 95% confidence intervals.

Results

As expected, the U23 group was faster on average across all trials in the Footbonaut. Table 2 displays both the performance in the skills assessment task in addition to the overall head movement means (SD) across the entire session (i.e., 32 trials). The results indicate that, although the older players used less extensive head movements per second compared to the younger age group across an entire trial, the U23's demonstrated more extensive head movements per second during the exploration phase but less extensive head movements per second during the possession phase compared to the U13's.

Overall

With all players analysed together, the results indicated that a three-variable model provided the best fit (Table 3). The model indicated that HTC:E (−0.020, 95% CI [−0.034, −0.005], $p < 0.01$), HTC:P^2 (0.006, 95% CI [0.003, 0.008], $p < 0.001$), and age group (−0.282, 95% CI [−0.339, −0.226], $p < 0.001$) collectively best explained time to completion. Specifically, more head turns before ball possession, less head turns during ball possession, and being an older player best predicted the speed of passing performance. As one of the variables that influenced time to completion was age group, a further investigation to what contributing variables within each age group was warranted.

U13 Group

The results indicated that a three-variable model provided the best fit (Table 3), with HTC:E (−0.027, 95% CI [−0.053, 0.000], $p = 0.05$), HTC:P^2 (0.007, 95% CI [0.004, 0.010], <0.001) and playing the midfielder position (−0.136, 95% CI [−0.264, −0.009], $p = 0.037$) collectively explaining time to completion. Specifically, more head turns before ball possession, less head turns during ball possession, and being a midfield player best predicted the speed of passing performance.

U23 Group

The results indicated that a two-variable model provided the best fit (Table 3), with HTE:E (−0.0004, 95% CI [−0.0008, −0.00008], $p = 0.015$) and HTE:P (0.0007, 95% CI [0.0001, 0.0013], $p = 0.019$) collectively explaining time to completion. Specifically, larger head turn excursion before ball possession and smaller head turn excursion during possession best predicted the speed of passing performance.

Table 2. Mean (SD) of the between group differences of head movements in the Footbonaut.

	Footbonaut		Head Movements					
	Score (%)	Avg. Speed (s)	Total Head Turns	HTF	Total Excursion	HTE	HTC:E	HTC:P
U13	70.00	2.48	278.57	1.81	9628.13	62.55	3.20	2.62
	(6.59)	(0.13)	(54.48)	(0.30)	(2152.31)	(12.77)	(1.74)	(1.86)
U23	83.31	2.13	250.38	1.70	8625.62	58.37	4.13	2.02
	(8.47)	(0.09)	(58.06)	(0.40)	(1982.81)	(12.78)	(2.01)	(1.54)

Note: HTF = Head Turn Frequency, HTE = Head Turn Excursion.

Table 3. Retained best subset selection model parameters that explain the largest effect of various visual exploratory actions, age and playing position on time to completion of each trial in the Footbonaut.

	Variable			Regression Model						
	Estimate	Std. Error	t-value	P value	Std. Error	DF	R2	Adj. R2	F value	P Value
Overall										
Intercept	2.368	0.032	73.677	<0.001	0.349	3, 647	0.206	0.202	55.81	<0.001
HTC:E	−0.020	0.007	−2.693	0.007						
HTC:P^2	0.006	0.001	4.846	<0.001						
Age Group: U23	−0.282	0.029	−9.835	<0.001						
U13										
Intercept	2.419	0.055	44.222	<0.001	0.393	5, 304	0.105	0.090	7.136	<0.001
HTC:E	−0.027	0.014	−1.963	0.05						
HTC:P^2	0.007	0.002	4.270	<0.001						
Playing Position: Midfielder	−0.136	0.065	−2.099	0.037						
U23										
Intercept	2.176	0.103	21.084	<0.001	0.295	4, 336	0.026	0.014	2.221	0.07
HTE:E	−0.0004	0.0002	−2.441	0.015						
HTE:P	0.0007	0.0003	2.357	0.019						

HTC:E = Head Turn Count: Exploration Phase, HTC:P^2 = Head Turn Count: Possession Phase Polynomial, HTE:E = Head Turn Excursion: Exploration Phase, HTE:P = Head Turn Excursion: Possession Phase.

Discussion

With the aim of understanding the role of visual exploration on football passing performance, the current study measured head movements and passing performance of high-level football players while they completed a standardised set of trials in the Footbonaut. Following previous research, VEA was determined both before the player had possession of the ball and while the player had possession of the ball. Further, analyses were conducted for U13 and U23 players together and separately. As expected, the older players completed passing actions more quickly than younger players. This finding is in line with previous investigations of performance in the Footbonaut (Beavan et al. 2019a) and is assumed to reflect the vast difference in playing experience between the two samples. Of greater interest to this investigation is the factors that contributed to this difference in performance, in particular the VEA variables that explained performance.

Overall, a higher head turn count before a player received the ball was associated with a reduced time to complete trials, whereas a higher head turn count after a player received the ball was associated with an increased time to complete trials. This finding supports the finding of McGuckian et al. (2019), who also found that more exploration prior to ball possession and less exploration when in ball possession, resulted in faster passing responses. Further, the differences in VEA with and without possession of the ball between U13 and U23 players (Table 2) suggest that older players explored their surroundings more extensively before gaining possession of the ball, which might have resulted in a reduced requirement to explore once they had gained possession of the ball. Together, these findings add support to the value of VEA as an important perceptual-motor ability and its role in the prospective guidance – i.e., *ahead* of time (Adolph et al. 2000; McGuckian et al. 2019) – of passing actions in football.

The analysis of only the U13 players also supports the importance of VEA before ball possession for successful prospective passing actions with the ball. Interestingly, playing position also significantly contributed to the speed of passing actions, with midfield players being able to complete passes more quickly than other playing positions. This finding was not replicated with the U23 group, which may suggest important implications from a perspective of talent identification and development of younger players. One explanation may be that the midfield players have developed this ability to complete passes more quickly due to the constraints they have been exposed to during their short playing career. That is, because their midfield role has higher pressure from opponents and a higher degree of 360-degree play during games than other positions, the midfield players have developed the ability to deal with these constraints with close ball control, high situation awareness and fast passing actions (Oppici et al. 2019). If this is the case, gaining a deeper understanding of how to develop this perceptual-motor attunement in younger players of all positions appears a worthy endeavour.

For the U23 group, the VEA variables that explained faster passing responses were larger head turns before gaining possession and smaller head turns when in possession of the ball. While these were the variables that contributed to faster performance within the U23 group, these players exhibited less extensive VEA than the U13 group (see HTF and HTE, Table 2). This finding suggests that the older players may be more attuned to the perceptual information required for future passing actions and are able to make better use of the information gained by their VEA. It might also be the case that the older players have developed strategies to make better use of this information, such as more efficient body orientation for the upcoming passing actions. This is in line with previous research demonstrating that highly experienced football players have the perceptual-motor coordination that allows them to orientate their attention towards player-directed areas during the reception phase of possession and only attend to the ball when performing the first touch (Oppici et al. 2017).

While the current study adds support to previous work relating to the value of VEA for football performance, there were limitations that should be considered when interpreting the findings. It is possible that the current investigation did not quantify potentially relevant exploration between trials. Between the end of one trial and the beginning of the next, players likely engaged in exploration for action orientation (see van Andel et al. 2019); however, this data was excluded from the current analysis, and it is suggested that future studies take this into account. Additionally, it needs mentioning that the current study did not control for exposure to the Footbonaut assessment environment. However, with consideration of these limitations, the current study has strength in the standardised and repeatable nature of the football passing task and extends the understanding of perceptual-motor performance in the Footbonaut.

Common across both controlled and representative studies is the finding that more extensive VEA is related to improved performance, and the rates of VEA between these studies appear to have some similarity (McGuckian et al. 2018b, 2019). However, it is important to emphasize that, while the Footbonaut offers experimental control, the perceptual information that is needed for performance in the Footbonaut may be different to the information that is available to a player during match-play (Dicks et al. 2009; Pinder et al. 2011; Travassos et al. 2013). In these scenarios, players attune themselves to perceptual information from many more relevant sources than are presented in the Footbonaut, and it needs to be established how this influences the contribution of VEA variables to passing performance between these scenarios. Further, passing performance during match-play is more complex than solely speed of responses. While the ability to complete passes quickly is certainly valuable, the accuracy and pass choice within the context of the game are also important aspects of performance.

The current study adds to the growing body of evidence for the value of VEA prior to ball possession in football. Here, the specific VEA variables that have the greatest contribution to the speed of passing responses in the Footbonaut were identified, and differences were shown between U13 and U23 players. Whilst the findings further our understanding of perceptual and passing performance in the Footbonaut, it is important to take note of the limitations in regard to generalising the findings to representative football training and match-play. It is therefore recommended that future research investigates the (shared and contrasting) exploration characteristics in standardised (i.e., Footbonaut-like) training drills, more representative training and match-play. Such research will also further promote our understanding of whether and how exploration behaviour transfers from standardised training scenarios to representative on-field settings.

Practical implications

Given the apparent value of VEA before ball possession as shown in various studies, and the observed passing speed reduction related to VEA when in possession of the ball, coaches should endeavour to develop training situations that encourage players to visually scan their environment before ball possession is gained. In doing so, coaches should aim to capture quantitative measures of VEA in training and games to ensure their training situations are representative of match-play. While this is important at all levels of football performance, particular emphasis should be placed on the development of VEA in younger players, as the development of optimal exploratory actions at younger ages will likely aid the performance of technical, tactical and physical aspects of performance.

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