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Karl Marius Aksum

Visual Perception in Elite Football

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Acknowledgements

I feel very privileged and humble to have had the opportunity to work on my PhD for the last 4 years. As I see myself as a practitioner and not an academic. It never crossed my mind that I would ever do research at this level. Now, after 4 years, I feel both drained and proud to submit this dissertation.

Being a medium academic, it is safe to say that I have required substantial and vital help and guidance during these 4 years. First of all, I would like to thank my head supervisor Geir Jordet. You have been part of this journey for the last 5 years, which started when you supervised my master's thesis in 2016. You are one of very few people for whom I have immense professional respect. Your position in football is something I look up to and strive to emulate. As a supervisor, you have been the perfect fit for me: direct, tough, honest, unambiguous, straightforward, and punctual. I will always remember what you said to me right before you decided to offer me the PhD position: *"You are not a good listener, and you act and say things before thinking them through. If you become my PhD student, you need to change everything you say and do."* I can honestly say that I have marginally improved in these areas.

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Oslo, May 2021

Karl Marius Aksum

List of Papers

Paper I

Jordet, G., Aksum, K.M., Pedersen, D.N., Walvekar, A., Trivedi, A., McCall, A., Ivarsson, A. & Priestley, D. (2020). Scanning, contextual factors, and association with performance in English Premier League Footballers: An investigation across a season. *Frontiers in Psychology*, 11, 2399. doi: 10.3389/fpsyg.2020.553813.

Paper II

Aksum, K.M., Pokolm, M., Bjørndal, C.T., Rein, R., Memmert, D. & Jordet, G. (in press). Scanning activity in elite youth football players. *Journal of Sports Sciences.*

Paper III

Aksum, K.M., Brotangen, L., Bjørndal, C.T., Magnaguagno, L. & Jordet, G. (2020). Scanning activity of elite football players in 11 v 11 match play: An eye-tracking analysis on the duration and visual information of scanning. *Manuscript submitted for publication.*

Paper IV

Aksum, K.M, Magnaguagno, L., Bjørndal, C.T., Jordet, G. (2020). What do football players look at? An eye-tracking analysis of the visual fixations of players in 11 v 11 elite football match play. *Frontiers in Psychology*, 11, 2624. doi: 10.3389/fpsyg.2020.562995

Summary

Background: The aim of the present dissertation was to contribute to the currently available research on visual perception in football by examining how elite football players gather information in real football match play through their gaze and scanning behavior. Specifically, this dissertation focused on the duration and location of visual fixations and the information and duration of visual exploratory scanning exhibited by elite male midfield players, as well as the scanning behavior and subsequent performance of elite male players in all playing positions, across different age groups, during non-restrictive 11 v 11 football match play. What we know about visual perception in football is largely based upon empirical studies that have investigated football players' visual search strategies in laboratory settings with more or less representative designs. These studies do not adequately consider the visual reality nor the relationship between perception and action that football players encounter during match play. Hence, this dissertation focuses on capturing football players visual–perceptual strategies in their actual competitive environment, with potential implications for future research designs and coaching practice. This dissertation uses Gibson's (1979) ecological approach to visual perception as a theoretical framework to guide the research questions and interpret the findings.

Objectives: This dissertation had one overall objective: to identify characteristics of the visual–perceptual processes of elite football players in their natural performance environment and ascertain how these processes relate to on-field performance and contextual variables. To reach this objective, five research questions were prepared and discussed: (1) How does scanning relate to on-field attacking performance? (2) What characterizes scanning behavior in different contexts and playing situations? (3) What characterizes the timing of scanning, and how does this relate to on-field performance? (4) What characterizes the duration of scanning and fixations in elite football midfield players? (5) What characterizes the location and information (i.e., number of teammates and opponents) of scanning and fixations in elite football midfield players?

Design and Methods: The overall designs of the papers involved quantitative video match analysis (Papers I and II) and eye-tracking analysis (Papers III and IV) conducted in non-restrictive settings during 11 v 11 match play. Additionally, Papers III and IV were exploratory case studies. In total, 85 players comprising elite-level senior male football players (Papers I, III, and IV) and elite-level youth male football players (Paper II) participated in this dissertation.

Results and Discussion: In Paper I, the findings revealed a positive relationship between players' scan frequency prior to receiving the ball and the subsequent pass completion rate. Additionally, attacking scan frequency changed as a result of positional demands (e.g., pitch position) and different contexts (i.e., opponent pressure). These findings support the idea that scanning in football is a part of the complex interaction that affects football performance. Moreover, the results suggest that coaches should focus on scanning as a tool to enhance players' ability to pick up important visual information. Paper II found similar results regarding scan frequency and pass completion as well as the relationship between scan frequency and different positional and contextual demands. Moreover, the findings showed that U19 players scanned more than U17 players and were able to conduct their last scan closer to the ball receiving moment. Furthermore, there was a positive relationship between players' ability to conduct the last scan closer to the ball receiving moment and a more forward-oriented body position when receiving the ball, suggesting that players were able to adjust their bodies to a more advantageous position when they had more updated information of their surroundings. In Paper III, the results showed that the action undertaken with the ball and the context of the ball at the moment of scan initiation was related to the duration of scanning. Moreover, we found that over 90% of scans lasted for 0.66 seconds or less and only

2.3% of scans included a fixation, suggesting that players are able to gather the required information without the need to foveally fixate surrounding objects and spaces when scanning.

Lastly, the results from Paper IV showed differences in fixation location and areas of interest when the ball was near compared to far away, and during attack compared to during defense. Furthermore, we found longer fixation durations when the players looked at more areas of interest (i.e., ball, teammate, opponent), suggesting the need for multiple informative sources when practicing football. Additionally, the results revealed that players had much lower average fixation durations than previously reported in both laboratory studies and in situ studies in other sports.

Conclusions: In summary, the present thesis provides new knowledge of the frequency, timing, duration, and information of scanning in elite football players. It also provides results from the first-ever study of the gaze behavior of elite football players in 11 v 11 match play. Overall, the findings suggest that future research on visual perception in football should strive to develop more representative designs in non-restrictive settings. Furthermore, coaches should aim to develop football players' skills with the help of complex contextualized exercises that include an abundance of information, as opposed to decontextualized and isolated exercises in which vital information is removed from the players.

Sammendrag

Bakgrunn: Det overordnede målet med denne avhandlingen var å bidra til det eksisterende forskningsfeltet på visuell persepsjon i fotball gjennom å undersøke hvordan fotballspillere, på elitenivå, ved bruk av visuelle fikseringer og visuelle eksplorerende søk, skaffer seg informasjon under kamp. Nærmere bestemt, så fokuserte denne avhandlingen på (1) varigheten og områdene for fikseringer, (2) varigheten og informasjonen fra eksplorative søk, (3) søksatferd og dets betydning for prestasjon hos spillere i alle posisjoner, i ulike aldre, i reelle kampsituasjoner, hos mannlige elitespillere. Tidligere forskning på feltet har hovedsakelig blitt gjennomført i laboratorier med mer eller mindre representative design. Disse studiene har ikke helt klart å fange den visuelle virkeligheten som fotballspillere møter i kampsituasjon, heriblant den viktige koblingen mellom persepsjon og aksjon. Denne avhandlingen forsøker derfor utelukkende å undersøke fotballspilleres visuelle perseptuelle strategier under reelle kampsituasjoner, og videre, hvilke implikasjoner dette kan ha for fremtidig forskning og trenerpraksis. Denne avhandlingen brukte hovedsakelig et økologisk rammeverk for visuell persepsjon (Gibson, 1979) for å guide de ulike forskningsspørsmålene, og for å diskutere de ulike funnene.

Mål: Hovedmålet med denne avhandlingen har vært å identifisere ulike kjennetegn ved den visuelle persepsjonen til fotballspillere, på elitenivå, i deres naturlige omgivelser, og hvordan dette henger sammen med prestasjon på banen og kontekstuelle variabler. For å nå dette målet, så ble fem forskningsspørsmål utarbeidet og diskutert: (1) Hvordan er søk relatert til prestasjon i angrep? (2) Hva kjennetegner søksatferd i ulike kontekster og spillsituasjoner? (3) Hva kjennetegner søkstiming, og hvordan er dette relatert til prestasjon? (4) Hva kjennetegner varigheten på søk og fikseringer hos midtbanespillere på elitenivå? (5) Hvor er det midtbanespillere på elitenivå fikserer blikket sitt, og hvilken informasjon finner de under søk?

Design og metode: Det overordnede designet for studiene var kvantitative undersøkelser i kampsituasjon 11 mot 11. Artikkel I og II var videoanalysestudier, mens Artikkel III og IV var øyebevegelsestudier designet som utforskende case studier. Totalt 85 mannlige spillere bestående av seniorspillere på elitenivå (Artikkel I, III, og IV) og ungdomsspillere på elitenivå (Artikkel II) deltok i avhandlingen.

Resultater og diskusjon: I Artikkel 1 viste resultatene at det var en positiv sammenheng mellom søksfrekvens før mottak av pasning og hvorvidt spillerne traff på den etterfølgende pasningen. I tillegg endret søksfrekvensen seg som et resultat av posisjonelle krav (e.g., baneområde) og ulike kontekster (e.g., pressavstand). Funnene støtter tanken om at søk i fotball er en del av det komplekse samspillet som utgjør fotballprestasjon. En implikasjon av funnene var at trenere bør ha søkelys på søk som et verktøy som kan hjelpe spillernes til å hente inn viktig visuell informasjon i kamp. I Artikkel II ble det funnet lignende resultater som i Artikkel I når det gjaldt både sammenhengen mellom søksfrekvens og vellykkede pasninger, og at søksfrekvens forandret seg som et resultat av ulike posisjonelle og kontekstuelle krav. Dessuten viste resultatene at U19-spillere søkte mer enn U17-spillere, og at de var i stand til å gjennomføre det siste søket før ballmottak nærmere selve mottaket enn U17-spillere. I tillegg ble det funnet en positiv sammenheng mellom evnen til å gjennomføre det siste søket nærmest mulig ballmottaket og en mer fremoverrettet kroppsposisjon ved mottaket. Dette funnet tydet på at spillerne brukte fordelen med å ha oppdatert informasjon rett før ballmottaket til å endre til en mer gunstig kroppsposisjon ved mottaket. I Artikkel III viste resultatene at lengden på søk endres, som et resultat av handlingen som gjøres med ball og ballens kontekst, i det øyeblikket spillerne startet søkene sine. Videre fant vi at over 90% av alle søk varte 0.66 sekunder eller mindre og at kun 2.3% av søk inneholdt fikseringer, noe som indikerer at søk ikke inneholder detaljert skarp informasjon (fikseringer) av rom og medspillere/motspillere. Til slutt viste resultatene i Artikkel IV at spillerne fikserte blikket sitt på ulike steder når ballen var nært kontra når ballen var lengre unna, og når man spilte angrep kontra forsvar. Videre viste resultatene lengre fikseringsvarigheter når spillerne så på flere informasjonskilder (i.e., ball, lagkamerat og motstander) om gangen, noe som impliserer nødvendigheten av at fotballtrening inneholder flere informasjonskilder. I tillegg viste resultatene at gjennomsnittlig fikseringsvarighet var mye lavere enn tidligere rapportert fra studier som er gjort i laboratorium, og fra studier som er gjort på felt i andre idretter.

Konklusjon: Denne avhandlingen har presentert ny kunnskap om søksfrekvens, søkstiming, og søksvarighet hos elitespillere i fotball. Den har også, gjennom å gjennomføre den aller første studien som har undersøkt hva spillere ser på under kamp, gitt ny kunnskap om hvordan fotballspillere bruker synet sitt i deres ekte prestasjonskontekst. Oppsummert så indikerer funnene fra denne avhandlingen at fremtidig forskning på visuell persepsjon i fotball bør streve etter å designe studier med et mer representativt design under normalt fotballspill, og videre, at trenere bør streve etter å utvikle spillere ved hjelp av komplekse funksjonelle øvelser der masse viktig informasjon er tilgjengelig, fremfor dekontekstualiserte isolerte øvelser, der viktig informasjon er fjernet fra spillerne.

Abbreviations

PiP	Player in Possession
VR	Virtual Reality
IMU	Inertial Measurement Unit
NSD	The Norwegian Centre for Research Data
STM	Short-Term Memory
LTM	Long-Term Memory
EPL	English Premier League
B/O/T	Ball/Opponent/Teammate
O/T	Opponent/Teammate
DFB	German Football Federation
IPT	Information Processing Theory
GPS	Global Positioning System

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1. Introduction

Never in modern history have we, as a species, been less perceptive of our surroundings than we are right now (LeBlanc et al., 2015). We are constantly looking at our smartphones, laptops, and electronic tablets, often completely unaware of what is happening around us. Contrary to the development of the ambient perception-suppressed society in which we now live is the increasing interest in visual perception in sport expertise (e.g., Klostermann & Moeinirad, 2020). It is now generally accepted that expert athletes are able to use their visual ability in a superior way when making sport-specific decisions (Mann, Causer, Hiroki, & Runswick, 2019). Moreover, qualitative accounts from expert football players substantiate the importance of visual–perceptual skills for anticipation, decision-making, and creative behavior for football performance (Tedesqui & Orlick, 2014).

> *I perceive the game in a different way. It's a question of viewpoints, of having a wide field of vision. Being able to see the bigger picture. Your classic midfielder looks downfield and sees the forwards. I'll focus instead on the space between me and them where I can work the ball through.* (Andrea Pirlo, Juventus and Italy, as cited in Pirlo & Alciato, 2014, p. 12).

> *Before you receive the pass, it's just taking looks around. You know which way to turn. You know which direction you're going. You know if there's a guy coming from your right or left if you are taking quick little snapshots.* (Christian Pulisic, Chelsea and USA, as cited in Wahl, 2018, p. 23).

The above quotes, provided by legendary Italian midfield maestro Andrea Pirlo and American dribbling wizard Christian Pulisic of Chelsea, provide a good way of explaining what initially triggered my fascination with the subject of this dissertation.

For me, and other hopeful footballers during the early 2000s, players like the aforementioned Pirlo, as well as Xavi, Scholes, and Zidane, were the epitome of footballers who could seemingly see the entire pitch at all times and, thus, never seemed to be temporally constrained when they received the ball. For me, as an average-level footballer who wanted to make the transition from striker to central midfielder, I found that the information overload, especially coming from opponents pressing me from every angle, was too much to handle.

Regardless of my early understanding of the importance of looking around when playing football, there was never any emphasis on this from coaches, teammates, or the media. Thus, when I was introduced to the topic of visual perception during my master's, many pieces came together. "Orientation," "searching," and "checking your shoulder" were all terms for what I now believe is the right way to address this concept, namely, "visual exploratory scanning," or simply "scanning." Scanning refers to all head movements away from the ball with the intention of gathering performance-related information from one's surroundings.

To understand why scanning behavior is important in match play, we can turn to the extant research on gaze behavior. Several peer-reviewed studies have provided clear evidence that football players focus their gaze on the player in possession (PiP) of the ball significantly more than any other fixation location (Mann, Farrow, Shuttleworth, & Wilson, 2009; Roca, Ford, McRobert, & Williams, 2011, 2013; Roca, Ford, & Memmert, 2018; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007). Consequently, the PiP and the ball itself should be considered the most attention-grabbing sources of information in football. However, in football, in which 22 players are constantly moving on a pitch that is approximately 6500 m^2, there are many different important sources of information to look for. Correspondingly, being able to look away from the most salient information in the game of football while remaining in control of the positioning/trajectory of the ball would then seem to constitute an obvious advantage over other players who are overly focused on the ball. This is the main idea behind scanning and the reason why, in studies of visual perception in football, each scan is measured from the position of the ball (and the PiP).

To date, research on visual perception in football has been conducted primarily in laboratory settings in which researchers measure the players' gaze behavior while watching video clips or pictures on a screen (e.g., Vaeyens et al., 2007). Together, these studies have provided important insights into the visual search strategies of players of different ages and levels of expertise. What the current literature lacks, however, is data on (1) how players in different playing positions scan during a match, (2) what players actually look at/for when they scan, and (3) what players visually fixate on when they play a match. Although several studies have investigated football players' visual perception and gaze behavior in more or less representative laboratory settings (for a review, see McGuckian, Cole, & Pepping, 2018), a key problem with much of the literature regarding visual perception in general, and gaze behavior in particular, is the transferability of findings from the laboratory onto the field (Hüttermann, Noël, & Memmert, 2018). Specifically, it is difficult, in a laboratory setting, to capture the visual reality that players experience during match play in which they are constantly moving and adapting to the dynamics of the game. This has led to previous research findings, using eye tracking technology in laboratories, to be both inconsistent and contradictory (McGuckian, Cole, & Pepping, 2018). Consequently, field studies, often informed by an ecological dynamical approach, has risen as an alternative to the laboratory based research in this field (e.g., McGuckian, Cole, Chalkley, Jordet, & Pepping, 2020).

Informed by an ecological approach to visual perception (Gibson, 1979), the overall aim of this dissertation was to identify characteristics of the visual–perceptual processes of elite football players in their natural performance environment and ascertain how these processes relate to on-field performance and contextual variables. By moving the research from the laboratory to the football pitch, this dissertation presents novel findings of the visual perceptual behavior of elite football players during actual match play. These findings have the potential to guide future coaching practices and research designs.

In particular, this dissertation examines five main research questions related to one or more of the research papers: (1) How does scanning relate to on-field attacking performance? (Papers I and II). (2) What characterizes scanning behavior in different contexts and playing situations? (Papers I, II, and III). (3) What characterizes the timing of scanning, and how does this relate to on-field performance? (Paper II). (4) What characterizes the duration of scanning and fixations in elite football midfield players? (Papers III and IV). (5) What characterizes the location and information (i.e., number of teammates and opponents) of scanning and fixations in elite football midfield players? (Papers III and IV).

The following chapters are organized as follows: In Chapter 2, a review of studies on gaze behavior and scanning in football conducted in somewhat representative settings is presented. In Chapter 3, the concept of vision and the two different approaches that dominates research on visual perception (ecological vs cognitive) are described. This chapter ends with a description of the combined aims of this dissertation. In Chapter 4, the methodology used in the four different studies included this dissertation is presented and discussed. In Chapter 5, the main results from the four different papers are presented. In Chapter 6, the combined results are discussed according to the research questions of this dissertation. This is followed by a discussion of limitations, theoretical and methodological implications, practical implications, suggestions for future research, and conclusions.

2. Prior Research on Visual Perception in Football

What is known about visual perception in football is largely based on gaze behavior studies in laboratories with more or less representable designs with the use of eye-tracking equipment. This chapter provides a chronological overview of these studies, as well as an overview of the empirical studies of scanning and head movements conducted in situ. The scope of this review is to present empirical peer-reviewed research on the visual perception of outfield football players in open-play situations. The review only includes studies in which the visual scene is moving (e.g., video clips, in situ). Thus, studies in which players were asked to respond solely to pictures are not included, as they present a very limited representation of a football player's visual reality. Furthermore, studies that exclusively examined goalkeepers' gaze behavior in closed situations (i.e., penalty kicks) are not included as they are regarded as beyond the scope of this dissertation.

2.1. Gaze Behavior Research

In their seminal paper, Williams, Davids, Burwitz, and Williams (1994) conducted the first attempt to investigate football players' visual perception in realistic simulations. Using video clips of 11 v 11 match play, the authors found that the inexperienced players looked more towards the ball and ball carrier, while the more experienced players looked more towards the movements and positioning of other players. Additionally, the more experienced players conducted more short fixations and more total fixations compared to the inexperienced players (Williams et al., 1994).

In 1998, Williams and Davids performed a study on visual search strategies in 24 football players divided into two groups based on their playing level. The purpose of the study was to investigate players' gaze behavior in different simulated microstates of play (e.g., 1 v 1, 3 v 3). The players looked at different attacking video clips and were told to imagine that they were a defender on the opposite team. The results showed no differences in visual search strategies between the different groups in the 3 v 3 scenario. However, in the 1 v 1 scenario, the more experienced group had higher search frequencies with more short fixations compared to the less experienced group. Furthermore, the results showed that an increasing number of players in the video scenario led to higher search frequencies, which the researchers attributed to players having to gather information from an increasing number of informative sources (Williams & Davids, 1998).

One three-part experimental study by Helsen and Starkes (1999) aimed to investigate whether visual–perceptual skills were a determining factor in football expertise. It should be noted that the classification of semi-professional players as experts in this study is questionable. Hence, I instead refer to that particular group as "more experienced." In the study, one group consisting of 14 male semi-professional football players and another group consisting of 14 male kinesiology students looked at pictures and video clips, which they were then asked to respond to. In the video experiment (Experiment 3), the participants were asked to stand in front of a 10 m × 4 m screen and respond to the tactical situation presented in the video with a tactical-technical solution. The results showed that the less experienced group switched their attention from one source of information to another significantly more often than the more experienced group. They also showed that the more experienced group was better at extracting early information from the video clips and turned their attention more towards the free space and less towards the ball during the response phase of the experiment. Based on the combined results of the three experiments, the authors argued that more experienced players were able to obtain more information from each fixation because they had stored football-specific knowledge in their memory, which allowed them to recognize sport-specific information quicker and more accurately than the less experienced students (Helsen & Starkes, 1999).

To determine the effects of visual search behavior and decision-making, Vaeyens et al. (2007) published a study in which they investigated 87 youth players (13–15.8 years old) divided into four groups based on their playing level. The players watched videos of different simulated attacking microstates of play (from 2 v 1 to 5 v 3). Results revealed massive differences in gaze behavior between the groups. In particular, the elite group focused their gaze more centrally compared to the other groups and thus used their peripheral vision to detect information to a lager extent. According to the authors, this strategy had two clear advantages: (1) the peripheral vision is quicker at detecting information compared to the foveal vision; and (2) by using the peripheral vision more extensively, one limits the time of rapid eye movements (saccades), which were considered by the authors to be periods in which information intake could not take place (Vaeyens et al., 2007). Additionally, similar to the results of Williams and Davids (1998), the study showed that the number of players visible in the video clips affected the players' visual search strategies: more players led to higher search frequencies (Vaeyens et al., 2007). Lastly, similar to the results of Williams et al. (1994), the elite group players switched their gaze between the ball carrier and other sources of information significantly more frequently than the less skilled groups (Vaeyens et al., 2007).

The influence of viewing perspective on football players' visual search strategies and decision-making was first demonstrated experimentally by Mann et al. (2009). Nineteen skilled adult male players from the same team were seated in front of a 2.45 m × 1.83 m video projection and asked to watch different clips of attacking microstates of play. Additionally, they were instructed to respond verbally to what they would have done if they themselves were in possession of the ball when the clip was paused. The clips were presented from an aerial and player perspective. The results showed that players spent more time looking at open space and conducted more fixations of shorter durations in the aerial perspective (alternating between the PiP and other information sources) compared to the player perspective. Additionally, players performed better decision-making in the aerial perspective compared to the player perspective (Mann et al., 2009).

In a study featuring the participation of the youngest football players to date, Savelsbergh, Haans, Kooijman, and van Kampen (2010) examined the visual gaze strategy and locomotion of 20 young, skilled male football players (mean age 11.8). In the experiment, the participants were asked to stand in front of a screen and then respond to 4 s video clips of a 4 v 4 game by moving in the direction they believed they would intercept the “pass.” The results showed that the players who performed better on the task looked more towards the ball, while the low-score group looked more towards the receiving player and the hips/upper body region of the PiP. This result contradicts the findings of Nagano et al. (2004), who found that expert players in a 1 v 1 in situ defensive situation look less toward the ball than novices. This also contradicted results from an 11 v 11 defensive video simulation that showed that more inexperienced players looked more toward the ball than experienced players (Williams et al., 1994). In spite of these discrepancies, the authors concluded that visual search behavior can be used as an indicator of talent identification in young football players (Savelsbergh et al., 2010).

Roca et al. (2011, 2013) published two similar studies that examined the gaze behavior and decision-making of professional, semi-professional, and amateur players in 11 v 9 attacking sequence video clips filmed from a central defender's perspective. In contrast to previous studies using this methodology, participants were asked to stand in front of a life-size video screen, making the environment more representative than previous studies have managed. In the same vein as Williams et al. (1994) and Vaeyens et al. (2007), the results showed that the more skilled group(s) used a visual search strategy with more fixations of shorter duration and switched their gaze more often between the PiP/ball and other informative sources compared to the less skilled groups (Roca et al., 2011, 2013). Moreover, the same visual search pattern found in the skilled group(s) was found in the far condition across all groups (Roca et al., 2013). Combined, this suggests that both skill level and player-to-ball distance impact the gaze strategies used by players when looking at video clips on a screen.

In a similar study, Krzepota, Stepinski, and Zwierko (2016) examined the fixations of experienced and less experienced players in 1 v 1 defensive video simulations. In the experiment, players were asked to stand in front of a 3.5 m × 3.5 m projection and watch a video of a player dribbling a ball. While watching the film, they were not instructed to perform an action, but were free to do so if they wanted to. The results from this study contradicted many previous similarly designed studies. For instance, experienced players fixated significantly more on the ball/foot region of the dribbling player compared to the less experienced group, thus contradicting the results of Williams et al. (1998), who found that experienced players fixated more on the hip region of the attacker. Furthermore, the results showed no difference between the fixation duration and number of fixations between the two groups, again contradicting previous results suggesting that more experienced players use a gaze strategy of more short fixations toward more locations of the display compared to less experienced players (Vaeyens et al., 2007; Williams & Davids, 1998; Williams et al., 1994). The authors recognized these discrepancies but made no attempt to provide a plausible explanation for them.

In a study that set out to bridge the gap between the visual perception and action of participants, Roca et al. (2018) created a design that required participants to move and physically act upon 11 v 11 life-size video clips from German top division matches. Forty-four professional and semi-professional players viewed simulated attacking sequences of play that were occluded at key moments and were told to imagine that they were in possession of the ball. Their decision-making was expressed both by playing the ball and by verbally confirming their action thereafter. Based on their decision-making, the gaze behaviors of the 11 least creative and the 11 most creative players were subsequently analyzed. The results showed that the most creative group had more fixations of shorter durations toward more locations of the screen compared to less creative players (Roca et al., 2018). This result correlates favorably with previous results comparing skilled and less skilled players in defensive simulations (i.e., Roca et al., 2011; Williams et al., 1994). Hence, more skilled and more creative players seem to have a visual gaze strategy with more short fixations on informative sources other than the PiP/ball compared to less skilled and less creative players when watching football video clips.

In another study, van Maarseveen, Oudejans, Mann, and Savelsbergh (2018) attempted to determine whether the performance on perceptual-cognitive football-specific video tests was linked to actual on-field performance. Twenty-two female elite youth soccer players played 3 v 3 matches where their performance was measured. Subsequently, the players viewed video projections of similar 3 v 3 simulations where the players' eye movements, anticipation, decision-making, and pattern recall were measured. In contrast to previous knowledge on expertise differences in perceptual-cognitive tasks (e.g., Mann, Williams, Ward, & Janelle, 2007), the results showed no relationship between playing performance and performance on any of the perceptual-cognitive skills tests. The authors concluded, based on these results, that in situ research might be more suitable than laboratory perceptual-cognitive tests (i.e., video simulations) when examining the perceptual-motor performance of athletes in football (van Maarseveen et al., 2018).

Collectively, these studies have shown that when football players' watch video clips on a screen, the duration and location of their fixations (gaze behavior) differs according to (a) level of expertise or experience, (b) distance between the player and the ball, (c) viewing perspective, (d) playing phase, and (d) number of players in the situation. However, a limitation of these studies is the many different research designs (e.g., microstates of play vs 11 v 11) and outcome variables (e.g., verbal response vs action response) used, which makes it difficult to find conclusive combined evidence as to what constitutes optimal gaze behavior in football. In a recent review of technology-based studies on visual perception in football, McGuckian, Cole, and Pepping (2018) found no conclusive evidence of differences in gaze behavior between different levels of expertise, possibly due to the various research designs and outcome variables used in the studies reviewed. Based on these findings, the authors suggest that in order to determine the actual gaze behaviors of football players, future research should move from laboratory to field-based settings and aim to explore the gaze behavior of football players in their natural performance environment (McGuckian, Cole, & Pepping, 2018).

Addressing the literature gap regarding the knowledge of the properties of fixations in football in actual match play environments, one of the aims of this dissertation is to provide new knowledge on the duration and location of fixations in

11 v 11 elite match play. Although over 80% of all research using eye-tracking technology in sports has measured the properties of visual fixations (Kredel, Vater, Klostermann, & Hossner, 2017), no single study has examined visual fixations during an actual full-scale football match without restrictions.

2.2. Visual Perception and Decision-making Research

In a seminal study that set out to determine the perceptual skills of players across different youth age groups (U9, U11, U13, U15, U17) at different levels (Premier League academy players and local players), Ward and Williams (2003) found that even in the youngest group (U9), the best players had superior perceptual strategies compared to the less skilled group. More specifically, when responding to a video simulation of different scenarios in which the video was occluded 120 ms before ball contact, players in the elite group were better at anticipating the direction of a pass and better at anticipating the direction of a dribble. The researchers concluded that visual–perceptual skill was a good determining factor to separate elite and less skilled players across different youth age groups and that pattern recognition is essential for high-level football performance (Ward & Williams, 2003).

Following these results, a second three-part experiment was conducted on 17 skilled and less skilled adult male football players, split into two groups (Williams, Hodges, North, & Barton, 2006). The participants were initially asked to view short video clips (6–12 s) of attacking sequences of play (both structured and unstructured scenarios). They were then shown 10 of these video clips again. In this latter recognition phase, participants were asked to indicate if they believed they had seen the clip before by pressing a response key. This procedure was replicated in the second experiment, except that the players in the video were now converted into light points. Results showed that skilled players more quickly and accurately recognized both the structured and unstructured video clips compared to the less skilled group. Furthermore, skilled players were also more accurate in recognizing the clips with the converted light points. The authors argued that these findings could be explained by the fact that skilled football players had developed a more elaborate football-specific knowledge base and quicker access to memory information than the less skilled players (Williams et al., 2006).

In the previous section, the major peer-reviewed research on gaze behavior and decision-making in football that has been conducted in controlled laboratory settings with somewhat representative designs (e.g., video clips) was reviewed. It is important to note that the laboratory visual search studies that first began using eye-tracking research on football (i.e., Williams et al., 1994), paved the way for the more ecologically valid ways of measuring eye movements that we can use today. Thus, without this initial groundbreaking research, we would not be where we are today. Collectively, these studies have provided important insights into how football players at different levels use their vision in different contexts in a controlled environment. However, concerns have been raised regarding the external validity of these results (Hüttermann et al., 2018; Kredel et al., 2017).

2.3. Limitations of Laboratory Research

We do not yet know whether it is possible to transfer findings from controlled laboratory settings to a real sport performance environment (Hüttermann et al., 2018). For instance, in sport, nearly five times as many gaze studies revealed no difference between fixation duration between experts and intermediates than revealed significant differences (Klostermann & Moeinirad, 2020). Similarly, in a review of technology-based visual–perceptual research in football, a majority of studies showed no differences in fixation duration or number of fixations between different skill levels

(McGuckian, Cole, & Pepping, 2018). Furthermore, it has been argued that laboratory research has been unable to provide any conclusive evidence as to whether football players' visual–perceptual skills differ between players of different levels of expertise (McGuckian, Cole, & Pepping, 2018).

Similarly, there are concerns that by moving the research into the laboratory, the functional coupling between perception and action is removed (van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). For instance, there is reason to suggest that if a sport-specific movement response is not included in a study's experimental design, then the results will derive only from the ventral stream (perception of objects) of the participants' brains and, thus, exclude the contribution of visual perception derived from the dorsal stream (guidance of action) (van der Kamp et al., 2008). For this reason, results from research in which participants are required to perform actions that are unrelated to the perceptual response from the video footage, such as moving a computer mouse (Williams et al., 1994), stomping on a mat (Williams & Davids, 1998), writing on a piece of paper (Ward & Williams, 2003), or moving a joystick (Savelsbergh, Van der Kamp, Williams, & Ward, 2005), may not capture all aspects of perception and action that players encounter during competition. Consequently, different researchers have expressed the need to examine gaze behavior and perception in sports away from the contrived laboratory settings and instead in more representative environments (Cañal-Bruland, Lotz, Hagemann, Schorer, & Strauss, 2011; Dicks, Davids, & Button, 2009; Eldridge, Pulling, & Robins, 2013; Klostermann & Moeinirad, 2020; Spitz, Put, Wagemans, Williams, & Helsen, 2016).

2.4. In Situ Eye-tracking Research

In 2004, Nagano et al. became the first researchers to examine gaze behavior in a dynamic football situation out on the pitch. Eight players (four experts and four novices) were stationed on the pitch and asked to try to prevent the dribbler from getting past them. Gaze behavior was analyzed when the stimulus player (the dribbler) performed his feints. The results showed that experts were more inclined to look for information away from the ball, thus having a wider field of vision compared to the novices. Moreover, experts set their visual pivot on the knee/hip region of the dribbler in order to anticipate the direction of the dribble more quickly; in comparison, the novices exclusively looked at the ball. The researchers argued that since the lower limb movements determine the ball's direction, a superior gaze strategy would be to look at those regions instead of the ball itself when attempting to anticipate the direction of the dribble (Nagano et al., 2004).

2.5. Scanning Research

In 2004, Geir Jordet published a doctoral dissertation titled *Perceptual Expertise in Dynamic and Complex Competitive Team Contexts: An Investigation of Elite Football Midfield Players* (Jordet, 2004). This was the first attempt to create a more representative design, away from the laboratories, in the research of visual perception in football. Part of this work was published in an international peer-reviewed journal the next year (Jordet, 2005). In that study, Jordet conducted an imagery intervention program of perception on three elite midfield players in which the concept of scanning in football was introduced for the first time. The author named this activity an "exploratory search," which was operationally defined as follows:

> *A body and/or head movement in which the player's face is actively and temporarily directed away from the ball, seemingly with the intention of looking for teammates, opponents or other environmental objects or events, relevant to the carrying out of a subsequent action with the ball.* (Jordet, 2005, p. 143)

In this case study, Jordet (2005) used a mixed method of video match analysis and interviews to create individually suited imagery compact disks for the different players. The players were filmed in match situations both prior to and after the intervention program. The results showed that two of the players increased their scan frequency, and two of the players were able to conduct their last scan closer to the moment they received the ball. Lastly, only one of the players improved their performance with the ball, which was measured on a subjective scale of 1 (lowest) to 7 (highest). Jordet (2005) suggested that this might have to do with the level of the players (a ceiling effect) or that imagery interventions were not specific enough for a direct transition to on-field performance. This seminal work launched what has become a key research area in recent years, presumably because it allows researchers to interpret visual perception based on quantitative analyses of football players' behaviors during match play.

In 2013, the first two non-invasive studies on scanning and performance were published (Eldridge et al., 2013; Jordet, Bloomfield, & Heijmerikx, 2013). Eldridge et al. (2013) investigated the scanning of three 14-year-old football players in a match situation and found that scanning behavior had a positive influence on performance with the ball: players performed more forward passes in their opponents' half and were more likely to turn with the ball if they had performed at least one scan before receiving the ball. However, similar to Jordet's (2005) study, the authors found no link between passing performance (if a pass was successful or not) and scanning

(Eldridge et al., 2013). In the same vein, Jordet et al. (2013) used video analysis to examine scanning frequency and performance in Premier League football players. One hundred and eighteen midfield and forward players were examined using close-up video footage. Combined, the results revealed that the scan frequency prior to receiving the ball coincided with the subsequent performance with the ball. More specifically, when players had a high scan frequency before receiving a pass, they performed more successful passes and more successful forward passes than when they scanned less frequently (Jordet et al., 2013).

In my master's thesis, conducted in 2016, I examined the scanning behavior of 45 youth players, aged 14–20, in one of the world's leading youth football academies, Ajax Amsterdam. The club provided me with 4K video films of the respective youth teams' matches, which I then used to analyze the scan frequency and passing performance of all outfield players. The results showed (1) a positive relationship between scan frequency and pass completion, (2) that tighter opponent pressure was linked to lower scan frequencies, (3) that central defenders and midfielders had the highest scan frequencies, and (4) that players conducted more scans when they received the ball in central areas compared to wide areas.

In 2017, Pocock, Dicks, Thelwell, Chapman, and Barker (2017) replicated the method used by Jordet 12 years prior and conducted an imagery intervention study on five elite academy players, obtaining similar results. Their results showed that the players increased their scanning frequencies after the intervention. However, once again, this increase did not translate into consistently improved performance with the ball. Thus, the researchers argued that an imagery intervention program was useful for improving vision for perception, but had no effect on vision for the coupling of perception and action (Pocock et al., 2017).

A recent study by Phatak and Gruber (2019) involved examining the scanning behavior and performance of 35 male midfielders in the 2016 European Championships using video footage from Wyscout played on a VLC media player. Expanding on the research method used by Jordet et al. (2013), the results showed that higher scanning rates had a positive influence on passing percentage. Furthermore, results showed that the scanning rates when the ball was on its path towards the analyzed player (referred to as a transition scan) correlated with fewer turnovers from the subsequent action performed with the ball. Combined, the authors found that scanning explained up to 4% of the variance found in both pass completion and turnover rate (Phatak & Gruber, 2019). Those findings supported, once again, the existing knowledge that scanning in attacking play has a positive influence on performance (Eldridge et al., 2013; Jordet et al., 2013).

A recent study by Rojas Ferrer, Shishido, Kitahara, and Kameda (2020) involved the first attempt to investigate visual exploratory head movements using a virtual reality (VR) headset. The researchers used a combination of Jordet's (2005) definition of scanning and McGuckian, Cole, Jordet, Chalkley, and Pepping's (2018) definition of head movement and measured the excursion of the players' head movements related to the ball using VR simulation. The results showed that amateur players turned their heads for a longer amount of time and with bigger excursions compared to beginners (Rojas Ferrer et al., 2020).

2.5.1. Head Movement Research

In recent years, an attempt has been made to automatize the detection of head movements during match play, as well as in laboratory settings, using an inertial measurement unit (IMU) placed on players' heads (e.g., McGuckian, Beavan, Mayer, Chalkley, & Pepping, 2020). This equipment has the potential to make the notations of head movements more objective, as well as to provide accurate results on head excursion. McGuckian and colleagues have published several studies using this technology, such as in an 11 v 11 youth training match (McGuckian, Cole, et al., 2020), an 11 v 11 adult training match (McGuckian, Cole, Jordet, et al., 2018), a Footbonaut (a machine with multiple ball dispensers that fires footballs at different speeds and trajectories towards a centrally stationed player on an artificial turf) (McGuckian, Beavan, et al., 2020), and a laboratory setting (McGuckian, Cole, Chalkley, Jordet, & Pepping, 2019). Collectively, these studies on head movements are so closely linked to scanning that results from these studies are somewhat comparable to those of scanning studies, as both methodologies provide numbers related to the frequency of players' head movements.

However, head movements, as operationally defined in McGuckian and colleagues' studies, are different from scanning head movements, first operationalized by Jordet (2005). First, research applying IMU technology does not examine head movements in relation to the ball and thus does not measure the concept of scanning, in which all scans are counted as movements away from and back towards the ball (Jordet, 2005). Instead, an IMU measures all head movements. For example, if a pass is played from one side of the pitch to the other and the player follows the ball with his head and eyes throughout its entire path, this would not be measured as a scan per definition (e.g., Jordet, 2005). In contrast, the same situation would be detected as at least one head movement by the IMU (e.g., McGuckian, Cole, Jordet, et al., 2018). Second, whereas a scan does not end before the player's gaze returns to the ball, the IMU measures every scan as at least two head movements (away from and back towards the ball) (McGuckian, Cole, Jordet, et al., 2018). Together, these differences in operationalizations have resulted in much higher head turn frequencies

(McGuckian, Cole, Jordet, et al., 2018) compared to scan frequencies (e.g., Phatak & Gruber, 2019) and cannot, therefore, be directly compared.

In a simulated receiving and passing experiment conducted in a laboratory in which participants were surrounded by four computer screens, the results showed that higher head turn frequencies led to quicker movement responses (McGuckian et al., 2019). In another study, conducted in a football-specific laboratory (the Footbonaut), players were asked to explore their environment before actually receiving a pass and passing the ball as fast as they were able to in an assigned direction (McGuckian, Beavan, et al., 2020). Similar to the findings of Phatak and Gruber (2019) and Jordet (2013), the results showed that a higher number of head turns was associated with better passing performance in both U13 and U23 players. Furthermore, in the U13 group, midfielders had both the quickest passing responses and the highest head turn frequencies, whereas in the U23 group, the bigger head movement excursions were found to be the most predicative of quicker passing responses (McGuckian, Beavan, et al., 2020).

In relation to the present dissertation, however, the most interesting results were produced by 11 v 11 match play studies by McGuckian, Cole, Jordet, et al. (2018) and McGuckian, Cole, et al. (2020). Interestingly, in the first study, the researchers found a positive relationship between head turn frequency and forward passes, that the three seconds before receiving the ball was the most influential when it came to the subsequent ball action, and that bigger head excursions meant that the players were more likely to turn with the ball and switch the play in a new direction (McGuckian, Cole, Jordet, et al., 2018). In the second 11 v 11 study, unexpected results emerged. Specifically, players were found to explore less in the middle third of the pitch than in the attacking or defensive third, and less in the central areas of the pitch than in wide areas (McGuckian, Cole, et al., 2020).

These results differ completely from those presented in my own master's thesis, in which scan frequencies were found to be highest centrally in the defensive third and middle third of the pitch and significantly lower wide in the attacking third of the pitch (Aksum, 2016). The results also contradict the reasoning of investigating central midfielders based on their central positioning, where they are surrounded by information in every direction (e.g., Jordet, 2005). There are two likely causes for these surprising results. First, contrary to previous studies, which have exclusively researched scanning in attack (e.g., Aksum, 2016; Phatak & Gruber, 2019), this study examined attacking and defensive head movements combined (McGuckian, Cole, et al., 2020). Second, the inherent difference between one scan (measured as a head movement away from and back toward the ball (e.g., Jordet, 2005) and one head movement (every movement of the head irrespective of the ball's position) is greater than previously assumed.

Collectively, these studies imply a positive role for scanning in football performance in attacking play. Additionally, they show that the activity of scanning is trainable even in contexts away from the pitch (e.g., Pocock et al., 2017). However, much uncertainty still exists about the relationship between scanning and performance. For instance, there is still considerable ambiguity in the results regarding whether scanning has a significant (Phatak & Gruber, 2019), partial (Jordet, 2005; Jordet et al., 2013), or no (Eldridge et al., 2013) positive impact on passing performance. Moreover, two of the most influential studies on scanning to date had only three participants each (Eldridge et al., 2013; Jordet, 2005). Thus, caution should be applied regarding the generalizability of those results.

In addition, although some research has been carried out on scanning in actual competitive settings (e.g., Phatak & Gruber, 2019), no published studies have examined (a) scanning behavior across different playing positions, (b) what players are looking at when they perform scans, or (c) the duration of scanning in different contexts. Hence, this dissertation intends to determine the extent to which scanning in attacking match play is a contributing factor to performance and whether scanning behavior alters as a function of playing position. Moreover, this dissertation examines the information that players scan for and the duration of these scans in different contexts during 11 v 11 match play.

3. Theoretical Framework

Followed by a brief introduction to the visual sense, this chapter describes and discusses the two main approaches to visual perception, namely the information processing approach and the ecological approach. The chapter ends with a presentation of the aim of this dissertation.

3.1. What is Vision?

As human beings, we use our senses to interact with the surrounding world. The most important sense in this regard is the visual sense (McMorris, 2004). We have the ability to see because light is reflected from different objects in the environment and projected into the eyes' pupils. From there, the light continues through our eye lens, which flips the image upside down and then subsequently projects the image onto the retina. A person's retina is full of specialized cells called cones and rods, which convert the incoming light to electric signals that transfer to the visual cortex in our brain (Holmqvist et al., 2011; McMorris, 2004; Panchuk, Vine, & Vickers, 2015). Contrary to a camera, which is able to capture high-definition images in which every part of the picture is focused, our eyes can only see images of high-definition in the fovea. The fovea is positioned at the bottom of the retina and has the highest concentration of cones and rods (Holmqvist et al., 2011).

Moreover, when we foveate (fixate) on an object, the foveal span is only approximately two degrees of the entire visual field, which is about the size of a thumbnail one arm's length away (Discombe & Cotterill, 2015). Away from the fovea, the quality of vision falls rapidly and continuously in our peripheral vision (Henderson, 2003). Consequently, as images can only be seen in high definition through the fovea, human beings are forced to move their eyes constantly, an average three to five times each second (Holmqvist et al., 2011). This purposeful activity of moving the body, head, and eyes to project clear images to the fovea is called gaze control (Panchuk et al., 2015).

In football, vision has been reported by sports science students to be one of the main tactical performance indicators across all playing positions (with the exception of full backs) (Hughes et al., 2012). When investigating vision in general, and vision in sport in particular, there are three types of eye movements that are relevant: fixations, smooth pursuits, and saccades. Fixations involve foveally gazing at a point of interest. Smooth pursuits are fixations on objects travelling in smooth motion. Saccades are rapid and voluntary eye movements from one fixation to the next (Duchowski, 2007). In the studies presented in this dissertation, only fixations and smooth pursuits are measured, analyzed, and discussed, as there is, to date, no reliable way of measuring saccades using mobile eye-tracking technology in a real performance environment, such as during football match play.

Lastly, as a bridge for the upcoming chapters, it should be noted that although football experts are better at utilizing sport-specific information than lower-level players (Mann et al., 2019), there seems to be no evidence of differences in general visual function between high-level players and low-level players (Helsen & Starkes, 1999; Ward & Williams, 2003). There are also no differences in visual reaction time between experts and less skilled football players (Helsen & Starkes, 1999). Hence, it can be assumed with a large degree of certainty that the perceptual differences found in athletes of different levels are not found as a result of differences in visual capabilities but instead as a result of the context-specific processing or understanding of what they are seeing.

3.2. The Information Processing Approach to Visual Perception

A research paradigm is the assumptions and intellectual structure upon which research in a field of inquiry is based (Kuhn, 1996). The philosophical background of the cognitive-psychological approach to perception is the Cartesian school of philosophy, which emphasizes that the reality in which we perceive is a form of mental reconstruction of the environment (Williams, Davids, & Williams, 1999). A traditional cognitive psychologist would therefore describe visual perception as accepting and coding sensory input from the visual sense with the use of long- and short-term memory situated in the visual cortex of the brain (Schmidt & Lee, 2005).

The main theory of perception used in the cognitive-psychological tradition is the information processing theory (IPT) (McMorris, 2004). Simply explained, the IPT suggests that all perception consists of sensory inputs (sensations) that are processed and coded inside the brain in order to make them meaningful (perception), which then leads to a motor response. Hence, a definition of perception, according to IPT, would be “the organization, interpretation and integration of sensory information” (McMorris, 2004, p. 33). Furthermore, this input–processing–output conceptualization of perception is often referred to as indirect perception (Haber & Hershenson, 1974). Visual perception will, according to this paradigm, always be indirect because the different sensations can only be made sense of when they are processed by the central nervous system with the use of memory (McMorris, 2004).

When discussing memory as a concept in cognitive and perceptual mechanisms in sport, we often distinguish between short-term memory (STM) and long-term memory (LTM). Central to LTM theory is that retrieval cues kept in STM facilitate rapid and reliable access to domain-specific information stored in LTM (Williams & Ford, 2013). When items are practiced and rehearsed in a sufficient way, they are transferred from STM to LTM, where the resilience to loss is much stronger and where they can be more permanently stored (Schmidt & Lee, 2005).

Research across different sports in non-representative settings has shown that experts possess superior sport-specific memory capabilities (Williams & Ericsson, 2005) as well as the ability to use this memory-based knowledge more efficiently (e.g., Bard, Fleury, & Goulet, 1994). For instance, more experienced football players have been shown to have more advanced LTM football-specific knowledge when viewing two-dimensional pictures of tactical football scenarios compared to less experienced football players (Lex, Essig, Knoblauch, & Schack, 2015). Furthermore, expert athletes are able to rapidly encode information from LTM, enabling access to the required information, which expands the available capacity in STM. Consequently, these experts are able to bypass the problems of working memory limits (Williams & Ericsson, 2005). Thus, with practice and repetition, memories become incorporated at a subconscious level. The use of this prior knowledge, which is categorized in mental structures, is called schemata (Pruna & Bahdur, 2016).

One of the benefits of using the IPT approach in researching visual perception in sports is that researchers are able to examine each part separately (input, processing, output) in controlled laboratory settings. As a result, this branch of research conducted in laboratory settings has provided extensive knowledge on gaze behavior and perceptual-cognitive differences between skilled and less skilled football players when viewing video sequences of football play on a screen (e.g., Roca et al., 2018; Williams & Davids, 1998).

3.3. The Ecological Approach to Visual Perception

3.3.1. From Dynamical Systems Theory to Ecological Dynamics

The dynamical systems theory (DST) is “an interdisciplinary framework, utilized to study coordination processes in physical, biological and social systems” (Davids, Araújo, & Shuttleworth, 2005, p. 537). It is based on advances in physics, mathematics, biology, and chemistry and can be used as a theoretical foundation for ecological psychological research (Spencer, Austin, & Schutte, 2012). This theory proposes that any behavioral act is an enormously dynamic construct involving an intwined hierarchy of huge perceptual and cognitive complexity (Pol et al., 2020; Thelen & Smith, 1994). A DST framework to learning and performance in football emphasizes discovery learning. Hence, players are encouraged to learn by exploring rather than passively receiving knowledge (Davids et al., 2005). As a result, the DST has been proposed as a way of explaining perception (Spencer et al., 2012).

One DST concept, called “soft assembly,” explains that behavior is always assembled from multiple interacting components that can be freely combined from moment to moment based on the context, task, and developmental history of the organism (Spencer et al., 2012). An example from a football context would be a 1 v 1 situation, which often occurs in a match between a dribbling winger and a defending full back. According to the DST, the decisions and moves that emerge in this kind of situation will be tailored to the performance context. Specifically, the winger will not dribble at an exact distance every time, but will instead use his or her intrinsic metric system to perceive the situation (i.e., the distance, body position, and speed of the defender), which in turn will help the player to decide when and where to try and dribble past the player (Davids et al., 2005).

The close link between DST and ecological psychology has given rise to the concept of "ecological dynamics," which has been referred to as a new and promising approach to understanding learning, development, and performance in sports (Dicks et al., 2009). This has resulted in novel approaches to football training, such as discovery learning (Davids et al., 2005) and game-based approaches (Renshaw, Davids, Newcombe, & Roberts, 2019). Hence, ecological dynamics provide us with a comprehensive understanding of perception in sport/football and its implications for practice and skill development. (Spencer et al., 2012).

3.3.2. Gibson's Ecological Approach to Visual Perception

James Gibson, often referred to as the founding father of ecological psychology, tried to explain the role of perception with as little reference to the nervous system as possible (McMorris, 2004). Consequently, an ecological psychologist would explain visual perception as the direct visual link between the observer and his or her surroundings without recourse to memory (Gibson, 1979). More specifically, according to this perspective, information is inherent in the ambient light when an observer looks at a visual scene (Agyei, van der Weel, & van der Meer, 2016). This way of studying visual perception, first proposed by Gibson in 1979, is referred to as direct perception because of the suggested direct, interdependent link between perception and action, often called perception–action coupling (Gibson, 1979). The perception–action coupling can be understood as the accurate and efficient relationship between the perceptual and motor processes of an individual (Pinder, Davids, Renshaw, & Araújo, 2011).

The most important concept in Gibson's theory of direct perception is the concept of affordances (Araujo & Davids, 2009). Affordances describe what the environment offers an individual in terms of movement solutions (Gibson, 1979).

They are simultaneously objective and subjective; objective because they exist independently of perception, and subjective because they are related to an individual's action capabilities (Osiurak, Rossetti, & Badets, 2017). Thus, it opposes Cartesian dualisms such as objective–subjective, body–mind, and input–output. According to Reed (1996), these affordances are embodied in objects surrounding an individual and work as behavior regulators. In order to exploit these affordances and act upon available information in the environment (e.g., the football match), the movement system requires an intentional action from the perceiver, referred to as an exploratory behavior, which can be described as a self-initiated movement that generates information and provides an opportunity for information to be acted upon (Adolph, Eppler, Marin, Weise, & Clearfield, 2000). Reed (1996) referred to this exploratory activity as the scanning for and use of information.

Taken together, the ecological psychological approach is the best fit for the design and interpretation of the findings of the studies included in this dissertation. However, the cognitive-psychological view cannot be excluded completely because memory is certainly a factor in most perceptual processes on a sports field (Schmidt & Lee, 2005). This statement is not in direct contradiction to Gibson because, although he questioned the science behind the premise of perception, he never denied the role of the central nervous system in perception (McMorris, 2004). In addition, it is important to note that while future technical innovations might give researchers the opportunity to study the brain's function in actual football match play (e.g., memory processing), there is no way of doing this online with today's technology.

Let us assume that the results of the studies presented in this dissertation suggest that elite football players are good at collecting visual information for subsequent performance with the ball. An explanation using the ecological paradigm could be that the best players are better at attaining this information because they are better at finding and utilizing the best affordances available in the display at the right time. A contrary explanation using the cognitive perception paradigm could be that the best players are more effective in attaining this important information because they are better and faster at processing the input they get from their vision than less skilled players, meaning they have both better and faster LTM and STM utilization. Both explanations seem valid, but only the ecological approach would give us a scientifically valid explanation, as there currently is no way to accurately measure a football player's memory/brain activity by looking at a recording of a match or by analyzing eye-tracking videos from the field of play.

3.3.3. Representative Design

In order to create research evidence worthy of generalizability, it has been argued that the study of organism–environment interactions, such as visual perception and decision-making, needs to be sampled from an organism’s (e.g., athlete’s) typical environment (e.g., the football pitch) (Brunswik, 1956). Representative design, when addressing sport psychology research, refers to the notion that the experimental task constraint that researchers insert into a study has to be representable of the performance environment that is the focus of the study in order for the results to be transferable to the real world (Pinder et al., 2011). Furthermore, Pinder et al. (2011) advocate that, as the participants of an experiment must be representative of the population in which the study wishes to generalize, the experimental task constraints inherent to the study must also represent the performance constraints to which they are to be generalized. Hence, it has been argued that in order to detect how athletes’ use their vision during sports performance, research has to be conducted in athletes’ actual performance setting (Kredel et al., 2017). However, contrary to this logic, only

39.4% of gaze behavior studies in sports have been conducted in natural viewing conditions (Kredel et al., 2017), and only 39% of studies using technology-based assessment of visual perception and exploration behavior in football involved participants performing a representative action (McGuckian, Cole, & Pepping, 2018).

3.4. The Aim of This Dissertation

The present dissertation has one overall aim:

> *To identify characteristics of the visual–perceptual processes of elite football players in their natural performance environment and ascertain how these processes relate to on-field performance and contextual variables.*

To reach this aim, five specific research questions are addressed:

1. How does scanning relate to on-field attacking performance?
2. What characterizes scanning behavior in different contexts and playing situations?
3. What characterizes the timing of scanning, and how does this relate to on-field performance?
4. What characterizes the duration of scanning and fixations in elite football midfield players?
5. What characterizes the location and information (i.e., number of teammates and opponents) of scanning and fixations in elite football midfield players?

4. Methodology

The present dissertation consists of four research papers, all aimed at examining visual perception and gaze behavior in elite football during match play. The dissertation as a whole was designed as an explorative and observational study. The four papers originated from three major data collections, conducted mainly by me, each of which had multiple data collection periods. In this chapter, the methodology used in the different papers is presented and discussed. First, an overview of the data collection methods used for Papers I and II (video match analysis) and Papers III and IV (eye-tracking analysis) are presented. Thereafter, the specific details of the participants, research designs, ethical considerations, and procedures are described.

4.1. Video Match Analysis

Video match analysis can be used to create data on physical, technical, and tactical areas related to performance (Carling & Court, 2013). The data for Papers I and II was collected from video footage of competitive elite-level matches in 4K resolution, filmed either by myself or a co-author (only for Paper I). The subsequent coding of the collected data differed between the two papers. In Paper I, we coded the scans and behaviors of the target player with a web-based program using player tracking technology. This was possible because the team we analyzed produced field-based coordinates for every player’s actions during the matches and because all matches were played at the same stadium. In comparison, in Paper II, we did all coding manually, meaning that we had to identify, zoom in on the target player, and manually code each situation. This sub-method used to research behavior in observational research is called tallying or frequency-counting, a method in which one systematically counts the occurrence of a clearly defined behavior in a specified time period (Thomas, Nelson, & Silverman, 2015).

The first study using video match analysis in football was conducted by Reep and Benjamin (1968). Since then, studies using this methodology have provided results on playing styles (Fernandez-Navarro, Fradua, Zubillaga, Ford, & McRobert, 2016), passing sequences (Hughes & Franks, 2005), technical actions (Konefał et al., 2019), physical actions (Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009), and player contributions (Clemente, Martins, Wong, Kalamaras, & Mendes, 2015). In contrast, the history of using video match analysis to measure scanning is relatively short. The first published study using this methodology was conducted by Geir Jordet in 2005. In his exploratory case study on three elite Norwegian football players, players were filmed in nine, 11, and 13 games, which resulted in a total of 536 analyzed game situations in which the players' scanning behavior was analyzed in the few seconds leading up to receiving a pass (Jordet, 2005).

In previous work preceding this dissertation, we found that television footage was not sufficient to ensure that scanning behavior was measured accurately and comprehensibly, especially in situations where the ball was far away from the player. Previous studies on the bachelor's and master's levels have revealed that this could lead to the exclusion of a substantial number of situations due to the fact that the target player is not necessarily visible throughout the full time period (e.g., Aksum, 2016). This is crucial because our goal was to investigate the scan frequency during a significant time period (minimum 5 seconds, preferably 10 seconds) to ensure that the individual frequencies identified in players were reflective of their normal exploratory behavior.

Unlike TV productions, in our data collection, we always attempted to film the games with the ball and as many outfield players as possible inside the video frame at any given time without zooming in. In doing so, we were able to analyze every scan of a particular player in the last 10 seconds before he received the ball, even in situations where the ball was 70 meters away from the player when the time period started. Thus, the importance of analyzing this behavior from a tactical view (where we see most of the players at all times) cannot be overstated. Hence, in Paper I and II, we conducted all the filming of all the matches ourselves.

In contrast, in their study of 35 male midfielders from the 2016 European Championships, Phatak and Gruber (2019) chose to exclusively use video footage from Wyscout and only analyze players when they were "visible." Consequently, their data material was dependent on what the television producer chose to focus on at any time and is, thus, insubstantial at best. However, if matches are filmed with a tactical view and high-resolution cameras (4K or 8K), there is less or even no need for researchers to conduct the filming themselves. This is massively beneficial for researchers who can quickly and easily access the data material required for these types of studies.

4.2. Eye-tracking Technology and Analyses

When attempting to investigate gaze behavior in athletes' actual performance environment using eye tracking, there will always be a trade-off between (a) optimizing the external validity of the research and (b) making sure that the objectivity and reliability of the measurements are sufficient (Kredel et al., 2017). The main problem with eye-tracking research conducted in laboratories is the inability to transfer findings in controlled experimental settings to an actual sporting environment (Hüttermann et al., 2018). The data from Papers III and IV in this dissertation was collected using the Tobii Pro Glasses 2 head-mounted eye tracker on elite-level Norwegian midfield players from two different clubs. The players wore the eye tracker in 11 v 11 match play with standardized rules on a full-size pitch. In doing this, we attempted to address the stated lack of research on field studies without restrictions and prioritize external validity over internal validity (Hüttermann et al., 2018).

The history of using eye-tracking devices in sport research dates back to a 1976 study of basketball players (Bard & Fleury, 1976). Since then, eye-tracking technology has been used to measure athletes' gaze behavior in many different sports, including boxing (Ripoll, Kerlirzin, Stein, & Reine, 1995), tennis (Abernethy & Russell, 1987), basketball (Laby, 2020), handball (Rivilla-García, Muñoz Moreno, Grande Rodríguez, Sanchis, & Sampedro, 2013), futsal (Corrêa, Oliveira, Clavijo, Letícia da Silva, & Zalla, 2020), ice-hockey (Martell & Vickers, 2004), and football (Williams & Davids, 1998). Recent technological advances have allowed eye-tracking research to move away from the laboratory, thus allowing more ecologically valid context-specific research to be undertaken (Discombe & Cotterill, 2015).

Almost all eye trackers available today use a video-based pupil and corneal reflection system (Holmqvist et al., 2011). This system is widely regarded as the most practical device available (Duchowski, 2007). Although pupil-only tracking is possible, corneal reflection tracking offers an additional reference point to the eye image, which compensates for small head movements. Consequently, this technology has been the preferred method since the early 1990s (Holmqvist et al., 2011). There are three types of corneal reflection eye trackers available: table-mounted, remote, and head-mounted (Discombe & Cotterill, 2015). Table-mounted systems are extremely accurate and reliable but require the participant to sit still. Remote systems allow the participant to move more freely, but are still restricted to a computer screen (Holmqvist et al., 2011). The head-mounted system allows the participant to move freely in any direction without being restricted to the laboratory (Discombe & Cotterill, 2015).

Data collection using head-mounted systems requires the participant to wear special glasses or a head-mounted camera attached to an external hard drive (Discombe & Cotterill, 2015). This allows the participant maximum mobility. If the equipment is small and lightweight, it can be used in real-life sporting exercises (Holmqvist et al., 2011). When collecting data for this dissertation (Papers III and IV), we attached the external hard drive to the shorts or the upper backs of the players to ensure maximum mobility and unrestricted play. Attaching the hard drive on the upper back with the use of a global positioning system (GPS) bib was found to be the optimal solution for player comfort and mobility (see Paper III, Figure 1).

4.2.1. Limitations of Head-mounted Eye-tracking Systems and Analyses

New technological advances in head-mounted eye-tracking systems allowed us to investigate gaze behavior in football players' actual environment (11 v 11), thus allowing research to be conducted with more representative designs (Brunswik, 1956). Prior to the completion of this dissertation, there had been no such studies published. One explanation for this gap in the research literature is the different limitations of eye-movement registration technology.

First, the equipment is vulnerable to too much sunlight, as this might interfere with the corneal reflection (Discombe & Cotterill, 2015). During the pilot tests for Papers III and IV, we witnessed this issue firsthand. The eye trackers worked perfectly in both rain and snow. Contrastingly, the gaze sample percentage was considerably reduced when we collected data under direct sunlight. Modern head-mounted eye trackers are designed to be outside in natural light and are only affected during extremely bright days (Discombe & Cotterill, 2015). Fortunately, during the data collection days, the light was favorable.

Second, the eye trackers are only able to capture the foveal gaze point of the wearer and, therefore, cannot measure what is processed through peripheral vision (Duchowski, 2007). Consequently, football research to date has mainly provided results about the direction and duration of foveal fixations (e.g., Roca et al., 2011; Roca et al., 2013; Williams et al., 1994). Hence, although the foveal eye position is often the equivalent of attention (Nakashima & Shioiri, 2014), human beings use their peripheral vision when their attention deviates from the gaze location (Vater, Williams, & Hossner, 2019). Thus, this integral limitation of eye trackers means that we are not able to differentiate between which actions are informed by foveal vision (overt attention) and which actions are informed by peripheral vision (covert attention) in actual football matches. For instance, longer fixations could mean that a player either conducts prolonged information processing through his or her fovea or uses his or her peripheral vision (Vater et al., 2019). Moreover, the deductions made from these findings and the resultant recommendations for practical applications could be misleading, as they are solely made from findings of the players' foveal gaze points.

4.3. Participants

For all the studies described in this dissertation, we were fortunate to be able to either recruit or gain access to elite-level players. Hence, all the players included in these studies were either top-level international football players in their age group or senior professional national- and international-level football players.

Paper I. Participants were 27 male professional elite-level football players from an English Premier League club, ranging in age from 17 to 32 (M = 25.66, SD = 4.26). This particular club had achieved an average league position of 5.2 in the last 5 years (2016–2020) and regularly participated in European competitions (UEFA Champions League and UEFA Europa League). The 27 participants included in the analysis were outfield players who received at least one pass in at least one of the matches we filmed.

Paper II. Participants were 53 male elite youth players, ranging in age from 16 to 19 (*M* = 18.0, *SD* = 1.15). They were all outfield players who played for one of the four teams that reached the final in the U17 and U19 European Championships in 2018. Being selected to play for the best national teams in the most prestigious age-specific European competition is indicative of these players being among the very best in Europe in their respective age groups. To be included in the analysis, the players had to be the recipients of at least one pass in their team's respective semifinal or final.

Papers III and IV. For these studies, we were able to recruit players from the highest national level in Norway who agreed to wear the eye-tracking glasses during 11 v 11 match play. Participants were five midfield players who were part of the first team squad of two Norwegian Premier League (Eliteserien) clubs. In Study 3, four of the players were included in the analysis, ranging in age from 17 to 23 years (M = 20.75, SD = 2.87). One of the players was excluded based on the criterion that players had to have been in the starting 11 of their respective teams at least once. In Study 4, all five players were included (17–23 years, *Mage* = 19.84, *SD* = 2.52). All five players had played at least one match for the U21 Norwegian national team at the time when the data was collected. Since the data collection, all five players have established themselves in the squad of a Norwegian Premier League team, where they have played between 33 and 137 matches (M = 86.2, SD = 42.16) to date (October 2020).

4.4. Research Design

This dissertation consists of four papers that should all be classified as observational research studies. In an observational research design, the participants' behavior is observed and coded in their natural environment (i.e., the football pitch) and then analyzed (Thomas et al., 2015). Additionally, Papers III and IV should also be classified as both case studies and field studies. A case study is a descriptive, interpretive, or evaluative research technique used to provide detailed information about an individual or a group of individuals where the aim is to determine the unique characteristics of the subjects (Thomas et al., 2015). A field study takes place outside the laboratory under natural or near-natural conditions of the performance environment (Hüttermann et al., 2018).

4.5. Ethical Considerations

All research included in this dissertation was approved by the Norwegian Centre for Research Data (NSD), reference numbers: 57718 (Paper I, Appendix A), 60888 (Paper II, Appendix B), and 52593 (Papers III and IV, Appendix C). All data was stored securely on external hard drives locked in a safe inside my own office. In Studies III and IV, participants signed written informed consent forms prior to the data collection (Appendix D). Written informed consent was not required in Studies I and II, as there was no interference from the researchers or any sensitive data being processed. In Study II, we contacted the respective national team head coaches by email with information about the study and a request that they inform the players about their participation (Appendix E). We also stated that if any player did not wish to participate, they could reply to the first author. No players expressed a wish to be excluded from the study.

4.6. Procedures

This section presents the procedures that were undertaken to gather the data material for the four different papers included in this dissertation. Explicit details regarding the coding of the data and the reliability measures that were taken to ensure optimal objectivity are not included, but can be found in the respective papers.

Paper I. Agreement to film the matches was made between the club and the first author. To ensure maximum filming quality, we filmed seven matches as pilot studies (five at the analyzed club's stadium and two at another stadium). This extensive pilot filming was necessary in order to arrive at a functional setup for the entire filming and data editing process, which was fairly complicated due to (a) the process of merging the tracking data provided by the club with our match footage, and (b) the creation of the coding program. In total, excluding the pilot filming, we filmed and analyzed 21 home games (13 Premier League games, six UEFA Europa League games, and two Carabao Cup games) of one English Premier League (EPL) club during their 2017/18 season. One additional match was filmed but could not be analyzed due to a technological error with one of the cameras.

We filmed the matches using three 4K video cameras: two Blackmagic Micro Studio 4K cameras, which were placed in a fixed position to cover half of the pitch each, and one Panasonic AG-UX90 4K camcorder that was manually moved from side to side to make sure that the ball and as many players as possible were inside the video frame at all times. We then merged the recordings from the two Blackmagic cameras using homography transformations and the Opencv package in Python 3.6

and combined the recording with hand-tagged field location coordinates provided by the club. We then used these coordinates to create a Python program that automatically zoomed in on the analyzed player and kept him in the middle of the screen. Furthermore, in order to code the players' behaviors, we created a web-based program using PHP and Javascript. The coders could log into this program online and choose the player and situation they wanted to code. The coding window consisted of two synchronized videos: (1) a close-up video of the player (left part of the screen) and (2) an overview video recording of the game (right part of the screen). The program coded the variables according to the time period of the videos. It also allowed coders to undo their work if they made a coding mistake.

Paper II. Data was gathered from the European U17 Championship (May 4–20) and U19 Championship (July 16–29) in 2018. Prior to the data collection, we received permission from the UEFA to film all matches. The project was conducted in collaboration with the German Football Federation (DFB). The first author filmed all analyzed matches on-site using a Panasonic AG-UX 4K camcorder from a position as high as possible near the halfway line of the pitch. The position of the camera, as well as the filming, was conducted to ensure that the ball and as many outfield players as possible were inside the video frame at all times (identical to the way we operated the overview camera in Paper I).

Papers III and IV. Prior to the data collection, we conducted two pilot studies. These studies showed the importance of attaching the eye-tracking battery in a secure and firm way and of having similar weather conditions throughout the data collection process. Contact with the respective clubs was made by the first and last authors via email and telephone.

Subsequently, we met with the respective clubs and agreed upon dates for the two data collections. All participants were chosen in collaboration with the coaching staff of the respective teams. We chose to analyze central midfield players exclusively. The reasons for selecting central midfield players were that (1) this is in line with previous research in the area (Jordet, 2005; Jordet et al., 2013; Phatak & Gruber, 2019); (2) midfield players are often positioned in the middle of the pitch surrounded by players in all directions; and (3) central midfield players are the most utilized players in attacking build-up play (Clemente et al., 2015).

Data was acquired from two training matches of 11 v 11 match play that was played on the full-size training pitches of the respective teams. One team played against a third-division team, while the other team played an internal training match against other first team players. Both matches were played with standard association football rules, with no coach intervention during play. The players wore a Tobii Pro Glasses 2 head-mounted eye tracker. The eye tracker was able to capture the eye movements of the players, as well as film their field of vision. Additionally, we used a Panasonic AG-UX90 4K camcorder to film the matches. The camera was stationed on a camera platform positioned near the touchline at the halfway line, approximately 5 m above the ground. The camera was used to triangulate data from the eye tracker camera and to ensure more reliability when measuring the distance between the player and the ball and between the player and the nearest opponent.

All players signed a written informed consent letter prior to the data collection. We tested the equipment on all the players before they warmed up for the matches. The testing included (a) fitting the glasses using the correct nose piece, (b) calibrating the glasses in the same light (outdoors) as they would experience during the match, and (c) allowing them to familiarize themselves with the equipment. The process of detaching the battery and glasses from one player and then attaching it and calibrating the glasses for the next player lasted approximately three minutes. In Paper III, we recorded two of the players for 20 minutes each and two of the players for 10 minutes each. In Paper IV, one additional player was analyzed for 20 minutes. The differences in duration were due to (a) the duration of the match, (b) the duration of the fitting process, and (c) the battery from the eye tracker becoming detached from one of the players and needing to be reattached and recalibrated. As neither study III nor IV analyzed the individual differences between the players, we decided to include all recorded data irrespective of duration.

5. Results

5.1. Paper I

Scanning, contextual factors, and association with performance in English Premier League footballers: An investigation across a season

Jordet, Aksum, Pedersen, Walvekar, Trivedi, McCall, Ivarsson, and Priestley (2020)

Objectives: The aim of this study was to examine how football players in an English Premier League club use visual scanning in real games and whether scanning impacts performance on the pitch. More specifically, we wanted to establish how scanning changes in different contexts, such as pitch location, opponent pressure, and playing position, as well as examine how scan frequency prior to receiving a pass impacts the following action with the ball.

Design: Video match analysis, quantitative study.

Method: Participants were 27 professional male elite players, aged 17–32 years (M = 25.66, SD = 4.26).

Results: The mean scan frequency of all players was 0.44 scans/second (SD = 0.30). A Kruskall–Wallis test revealed significant differences between the different playing positions (H = 669.97, p < 0.001): central midfielders had the highest means, followed by central defenders, wingers, full backs, and forwards.

A Kruskall–Wallis test revealed that opponent pressure had a significant impact on scan frequency (H =319.90, p < 0.001). Post hoc pairwise comparisons showed significantly lower scan frequencies when the closest opponent was 0–1 m away and 2 m away compared to all other groups of opponent pressure ($p < 0.002$). Furthermore, players showed a steady increase in scan frequency from 0–1 meters up to 4 meters, where a further increase in distance was not associated with higher scan frequencies.

Only small differences in scanning were found when examining game state and game time. The results revealed significantly higher scan frequencies when a team was losing compared to when a team was drawing (p = 0.020, $d = 0.08$). Additionally, players tended to perform fewer scans in the closing minutes of the first half (45+) when they were losing ($H = 25.69$, $p = 0.001$).

Taken as a whole, the results showed that higher scan frequencies prior to receiving the ball were associated with better subsequent performance with the ball. First, players scanned significantly more frequently before conducting a forward action (0.46 s/s) compared to a backward action (0.42 s/s) (Kruskall–Wallis $H = 30.602$, $p < 0.00$). Second, the results showed that the players scanned significantly more frequently when their last action was a pass compared to a dribble ($p < 0.001$, $d = 0.08$), receiving the ball ($p < 0.001$, $d = 0.10$), or finishing ($p < 0.001$, $d = 0.19$). Third, when only looking at the different types of passes, the results, with Bonferroni-corrected adjusted significance values, showed that players scanned more frequently before playing long penetrative passes compared to backward passes ($p < 0.001$, $d = 0.24$), sideway passes ($p < 0.001$, $d = 0.23$), or short penetrative passes ($p < 0.001$, $d = 0.19$). Additionally, players scanned more frequently before performing a forward pass without penetration compared to a backward pass ($p < 0.001$, $d = 0.15$). Fourth, we also examined whether the last action of the players led to possession being maintained or lost. Results showed that players scanned significantly more frequently when possession was maintained (0.46 s/s, SD = 0.30) compared to when possession was lost (M = 0.37 s/s, SD = 0.30).

We also performed a more sophisticated analysis of the association between pass completion and scan frequency. A hierarchical Bayesian model with multiple explanatory variables showed that pass completion was significantly associated with higher scan frequencies. Hence, players who scanned more had a higher probability of completing a pass. However, this effect was small.

Limitations: There are a couple of limitations to this study. First, the analyzed data is only from one team. Thus, although the number of analyzed situations in this study is high (9574), there is no way of knowing whether analyses of players from a team that plays a different brand of football would yield similar results. Second, although many measures of reliability between coders were conducted, there is always the possibility of human error when a number of different individuals conduct manual coding on scanning in a complex and fluid environment. Accordingly, some caution must be taken when interpreting the findings.

Conclusion: The findings of this study indicate that there was a positive association between scan frequency prior to receiving the ball and subsequent performance with the ball for elite football players across all outfield positions in an EPL team. Specifically, higher scan frequency meant a higher probability of players completing the following pass. Moreover, higher scan frequencies were positively associated with more forward actions and maintaining possession for the team. Additionally, results showed that scanning was highly impacted by the context that the players experienced on the pitch (opponent pressure, pitch position) and their playing position, suggesting that scanning in football has to be measured and trained in the context of the game.

5.2. Paper II

Scanning Activity in Elite Youth Football Players

Aksum, Pokolm, Bjørndal, Rein, Memmert, and Jordet (in press)

Objectives: The aim of this study was to examine the scanning behavior of elite youth football players in the most competitive match setting available. More specifically, we wanted to examine how scanning is related to performance according to situational, context-specific, and temporal constraints in 11 v 11 match play.

Design: Video match analysis, quantitative study.

Method: The participants were 53 male elite youth players (M*age* = 18.0, *SD* = 1.15): 24 players from the U17 European Championship (M*age* = 16.9, *SD* = 0.40) and 29 players from the U19 European Championship (M*age* = 18.9, *SD* = 0.40).

Results: The players in this study performed, on average, 0.42 scans/second in the seconds leading up to receiving a pass. When comparing the data from the different championships, the results showed that U19 players (*M* = 0.45, *SD* = 0.29) performed significantly higher scan frequencies than U17 players (*M* = 0.36, *SD* = 0.30).

The results showed a positive association between higher scan frequency and pass completion. A mixed-effects logistic regression analysis showed that players had significantly higher scan rates when they made a successful pass (0.43 s/s) compared to when they made an unsuccessful pass (0.36 s/s), $\chi^2(1) = 8.0$, $p < 0.01$. Furthermore, the same results on pass completion and scan rate were only evident when examining the forward passes (long breakthrough, short breakthrough, and forward without breakthrough) ($n_{player} = 51$, $n_{forwardpass} = 1000$), $\chi^2(2) = 13.60$, $p < 0.01$).

On average, the players in this study touched the ball 2.5 times (*SD* = 2.65) when they received a pass. A small, but significant effect was found, revealing that more scans were associated with more touches when receiving the ball.

A linear mixed model showed that scan frequency was significantly associated with body orientation in the moment players received the ball, $\chi^2(1) = 30.10$, $p < 0.001$. A Tukey post hoc analysis showed that players had lower scan frequencies when they received the ball when facing their own goal (backwards) compared to sideways, $z = -0.1$, $SE = 0.02$, $p < 0.001$, or forward, $z = -0.11$, $SE = 0.02$, $p < 0.001$. Furthermore, we analyzed whether the time period between the last scan before receiving the ball was associated with the players' body positions at the exact moment of receiving. Results showed that players conducted their last scan significantly closer to the moment of ball reception in situations where they received the ball in a forward body position ($M = 1.49$ s) compared to a sideways body position ($M = 1.83$ s), $z = -0.3$, $SE = 0.1$, $p < 0.01$, or a backward body position ($M = 2.11$ s), $z = 0.6$, $SE = 0.12$, $p < 0.001$.

The results from a linear mixed model revealed a significant association between grouped opponent pressure and scan frequency, $\chi^2(3) = 67.0$, $p < 0.001$. A post hoc Tukey analysis revealed that significantly lower scan frequencies were found in situations with tight pressure compared to those with loose pressure ($p < 0.001$, $d = 0.47$) or no pressure ($p < 0.001$, $d = 0.37$), as well as in medium pressure compared to loose pressure situations ($p < 0.01$, $d = 0.21$).

The results for scan frequency and playing position revealed significant differences between the different playing positions, $\chi^2(2) = 27.80$, $p < 0.05$. A post hoc Tukey analysis showed that central defenders scanned significantly more frequently than full backs ($z = 0.14$, $SE = 0.02$, $p < 0.001$) or strikers ($z = 0.18$, $SE =$

0.03, $p < 0.001$), that central midfielders scanned significantly more frequently than full backs ($z = 0.17$, $SE = 0.02$, $p < 0.001$) or strikers ($z = 0.21$, $SE = 0.03$, $p < 0.001$), and that wingers scanned significantly more frequently than full backs ($z = 0.10$, $SE = 0.03$, $p < 0.01$) or strikers ($z = 0.14$, $SE = 0.03$, $p < 0.001$). In the same vein, pitch position was shown to influence the scan rates of the players. Players had, on average, higher scan frequencies in the two central areas compared to the wide areas.

Lastly, the timing of the initiation of the players' last scan before receiving the ball was analyzed. Across all situations where at least one scan was conducted, the average time of last scan initiation was 1.7 seconds before receipt of the ball. A linear mixed model revealed that the U19 players performed their last scan significantly closer to receipt of the ball than the U17 players, $\chi^2(1) = 13.61$, $p < 0.001$.

Limitations: Among the limitations of this study are the limited possibility of determining causal effects and the human errors that can occur during the coding of such a complex concept as scanning. Thus, inferences should be cautiously drawn.

Conclusion: The findings of this study suggest that scanning behavior changes as a function of different naturally occurring contexts found in a football match (i.e., playing position, pitch position, and opponent pressure), age level. Furthermore, higher scan frequency before receiving the ball meant that players made more successful passes overall as well as more successful forward passes. Additionally, the results showed that less time between the last scan and ball reception meant that players were more likely to receive the ball in a forward-directed body position.

5.3. Paper III

Scanning activity of elite football players in 11 v 11 match play: An eye-tracking analysis on the duration and visual information of scanning

Aksum, Brotangen, Bjørndal, Magnaguagno, and Jordet (in review)

Objectives: The main aim of this study was to investigate the scanning behavior of elite football players in a naturally occurring context, using portable head-mounted eye trackers during 11 v 11 football match play. More specifically, we wanted to analyze the duration and visual information of scanning. A secondary aim was to address the absence of field study research without restrictions. This exploratory case study is the first to examine the concept of scanning using eye-tracking technology.

Design: A quantitative, exploratory, in situ case study.

Method: Participants were four elite male central midfield players from two Norwegian Premier League clubs, aged 17–23 years (M = 20.75, SD = 2.87).

Results: Taken together, the players in this study conducted 869 scans with a mean duration of 39.65 centiseconds (cs) (*Mdn* = 34 cs, *SD* = 28.42). Moreover, 90.3% of all scans lasted between 2 and 66 cs. The results further revealed that scanning duration alters as a function of different contexts. First, a Mann–Whitney U test revealed that players exhibited significantly longer scanning durations when a pass was ongoing compared to when the ball was under the control (in possession) of a player, $U = 106293.5$, $z = 5.54$, $p < 0.001$, $\eta_p^2 = .04$. Second, a Kruskall–Wallis test, with subsequent post hoc pairwise comparisons, revealed that players scanned for significantly longer durations when the scan was initiated when the ball was on its

path between two players compared to when a player had possession of the ball without touching it ($p < 0.001$). Third, significantly longer scanning durations were found when the ball was up in the air compared to when the ball was on the pitch at the moment of the initiation of the scan $U = 83227$, $z = 2.41$, $p = 0.016$, $\eta_p^2 = .01$. In total, only 20 (2.3%) scans involved visual fixations. A Mann–Whitney U test revealed that scans that included fixations were significantly longer than scans that did not include any fixations, $U = 14864$, $z = 5.79$, $p < 0.001$, $\eta_p^2 = .04$.

Separate Mann–Whitney U tests were conducted to test the relationship between scanning duration and playing phase, as well as scanning duration and player-to-ball distance. The results revealed that there was no statistical difference between scanning duration when the ball was near or far away, $U = 66341.5$, $z = .80$, $p = 0.44$, $\eta_p^2 < .001$. Furthermore, no statistical difference was found in scanning duration between the attack and defense playing phases, $U = 88370$, $z = -.46$, $p = 0.65$, $\eta_p^2 < .001$.

We analyzed the number of visible opponents and teammates inside the video frame in different phases of the scans and in different contexts using three-way ANOVA’s on playing phase (2) × player-to-ball distance (2) × number of players (2) on each of the scan’s phases (movement and stop point) and for the attention moment (foveal circle stop point). For the movement phases, the analysis showed a significant main effect for the playing phase, $F(1, 857) = 29.23$, $p < 0.001$, $\eta_p^2 = .03$, a significant main effect for the number of players, $F(1, 857) = 28.68$, $p < 0.001$, $\eta_p^2 = .03$, and an interaction between the playing phase and the number of players, $F(1, 857) = 8.71$, $p = 0.003$, $\eta_p^2 = .01$. This means that during the movement phases of their scans, the players’ video frames included significantly more players in attack compared to in defense and significantly more opponents than teammates during attacking scans.

For the stop point phase, the analysis revealed a significant main effect for the number of players, $F(1, 857) = 50.39$, $p < 0.001$, $\eta_p^2 = .06$, and the interaction of the playing phase and number of players, $F(1, 857) = 31.95$, $p < 0.001$, $\eta_p^2 = .04$. This indicates that significantly more opponents than teammates were visible inside the video frame at the stop point of the participants' attacking scans. For the foveal circle stop point, where it can be assumed that the participants' attention is directed towards, the results showed that there was a significant main effect for the playing phase, $F(1, 747) = 7.32$, $p = 0.007$, $\eta_p^2 = .01$, as well as a significant main effect for the number of players, $F(1, 747) = 4.28$, $p = 0.039$, $\eta_p^2 = .01$. This means that significantly more opponents than teammates were visible inside the video frame and that significantly more players were visible in defense compared to in attack in the foveal circle stop point of the participants' scans.

Limitations: Among the limitations of this study are the low number of participants (four) from a heterogeneous group (central midfielders), the inability to explain any causal relationship between the results of scanning information on (a) decision-making and (b) performance, and the operationalization used for the concept of scanning, which might have excluded some scans from the analysis.

Conclusion: The findings of this study reveal novel data on what elite midfield players look at, and for how long, during their information-collecting scanning behavior in an 11 v 11 match. Although exploratory in nature, this study showed that scanning behavior alters as a function of the context of the ball and the action undertaken with the ball at the moment of scan initiation. Moreover, surprisingly, no differences in scanning duration were found in relation to player-to-ball distance or playing phase, suggesting that scanning might occur in a similar way in attack compared to in defense, as well as in situations where the ball is near compared to far away from the players. Most noteworthy is the result showing that only 2.3% of scans involved fixations. This result might have massive implications for how coaches should train scanning ability in their players. Lastly, this study showed that the different phases in a scan provide different information to the players and that, in general, more opponents than teammates were visible inside the participants' video frame during scans, suggesting that opponents are potentially a more important information source than teammates when playing football.

5.4. Paper IV

What do football players look at? An eye-tracking analysis of the visual fixations of players in 11 v 11 elite football match play

Aksum, Magnaguagno, Bjørndal, and Jordet (2020)

Objectives: The principal aim of this study was to expand the knowledge of the gaze behaviors that football players use in their representative performance context (11 v 11 match play). Specifically, this study aimed to examine the duration and location of visual fixations within the naturally occurring contexts of a football match, using head-mounted eye-tracking technology.

Design: A quantitative, exploratory, in situ case study.

Method: The participants were five elite male central midfield players from two Norwegian Premier League clubs, aged 17–23 years (M = 19.84, SD = 2.52).

Results: The descriptive results showed that the average duration of fixations for all players was 242.29 milliseconds (ms) (SD = 195.03, Min. = 120 ms, Max. = 2400 ms). ANOVAs were used to test differences in fixation duration in different contexts. A one-way ANOVA on playing phase (2) showed no significant difference between fixation duration in attack and defense. A one-way ANOVA of player-to-ball distance showed that players conducted significantly longer fixation durations in the far condition (25–58 m) compared to the near condition (0–24 meters).

As a consequence of the significant three-way interaction effect found from the three-way ANOVA on areas of interest (4) × distance (2) × playing phase (2), two-way ANOVAs on areas of interest (4) and distance (2) were conducted separately for each playing phase. In defense, the results showed a significant effect only for areas of interest, $F(3,16) = 134.53$, $p < 0.001$, $d = 10.06$. Subsequent pairwise comparisons with Bonferroni-corrected *p*-values revealed significant differences between all numbers of areas of interest (*p*s < 0.032). More specifically, most of the time, players in defense fixated on two areas of interest, followed by three, one, and zero areas of interest. In the attack phase, the results revealed a significant effect on areas of interest, $F(3,16) = 130.94$, $p < 0.001$, $d = 9.93$, and an interaction effect, $F(3,16) = 5.25$, $p = 0.010$, $d = 1.98$. As a consequence of the interaction effect, two separate one-way ANOVAs on areas of interest (4) were conducted for the near and far distance conditions. Results revealed significant differences between the different areas of interest in both the near ($F(3,16) = 72.58$, $p < 0.001$, $d = 7.40$) and far ($F(3,16) = 53.47$, $p < 0.001$, $d = 6.32$) conditions in attack. In the near condition, the players fixated most on two areas of interest, followed by three, one, and zero areas of interest. The comparisons were all significant (*p*s < 0.008), except between zero areas and one area of interest ($p = 0.058$). In the far condition, the players fixated significantly more on two and three areas of interest compared to one or zero areas of interest. However, contrary to the near condition, there were no differences found between two and three areas of interest or between one and zero areas of interest.

To examine percentage viewing time and fixation duration in relation to fixation location, two three-way ANOVAs on fixation location (8) × distance (2) × playing phase (2) with repeated measures on the last two factors were conducted. The analysis revealed a significant three-way interaction on percentage viewing time, $F(7,32) = 2.66$, $p = 0.027$, $d = 1.53$, which meant that the percentage viewing time on the different fixation locations and distances differed in the different playing phases. Consequently, we conducted two-way ANOVAs on fixation location (8) × distance (2) with repeated measures on the latter factor for both attack and defense. Significant effects between the fixation locations were found in both attack, $F(7,32) = 114.56$, $p < 0.001$, $d = 10.06$, and defense, $F(7,32) = 81.86$, $p < 0.001$, $d = 8.45$.

In total, in both playing phases and in both distance conditions, the players spent most of their time viewing the PiP, followed by the ball/opponent/teammate (B/O/T) category. For fixation duration, the analysis revealed a significant effect between the different groups of fixation locations, $F(4,40) = 3.46$, $p = 0.004$, $d = 1.29$. Moreover, the analysis revealed that significantly longer fixations were conducted in the far condition than in the near condition, $F(1,40) = 5.97$, $p = 0.018$, $d = 0.64$. Bonferroni-corrected pairwise comparisons between the different fixation locations (8) revealed that players had significantly shorter fixation durations when viewing open space compared to B/O/T ($p < 0.001$), PiP ($p = 0.003$), and opponent/teammate (O/T) ($p = 0.014$).

Limitations: Among the limitations of this study are the inability to capture any causal relationships between gaze behavior and performance, the lack of controlling for game dynamics interference, such as leading or trailing, the design’s inability to capture fixation frequency, and the possible inaccuracies of the technological equipment we used, which has never previously been used in such a dynamic setting.

Conclusion: The findings of this study revealed that elite midfield players looked at different numbers of areas of interest, as well as different fixation locations, when the ball was near compared to far away and when playing in the attacking phase compared to playing in the defensive phase. Additionally, this exploratory case study revealed that players, on average, performed shorter fixations than previously reported in laboratory-based research designs, as well as in previous in situ designs in other sports. The players used longer fixation durations when they looked at more areas of interest compared to zero or one area of interest. These results suggest implications for future research design, as well as practical implications for practice design.

6. Discussion

This chapter discusses the findings that emerged from the statistical analysis of all the papers (Papers I, II, III, IV) presented above. The chapter is divided into five main sections, each of which presents the results relating to one of the research questions. Research on visual perception in football mostly consists of empirical studies investigating visual search strategies using eye-tracking equipment in laboratory settings (for a review, see McGuckian, Cole, & Pepping, 2018). Combined, these studies have examined how the way in which football players search the visual display is influenced by different constraints and situational probabilities, such as the number of players (Mann et al., 2007; Vaeyens et al., 2007; Williams & Davids, 1998), their level of expertise (Cañal-Bruland et al., 2011; Helsen & Starkes, 1999; North, Williams, Hodges, Ward, & Ericsson, 2009), and the player-to-ball distance (Roca et al., 2011, 2013; Vater, Roca, & Williams, 2016). In a recent review, McGuckian, Cole, and Pepping (2018) found that, taken together, laboratory research conducted on visual perception in football has provided vastly different results on gaze behavior related to playing level. Moreover, they found that none of the 38 studies included in the review were conducted in open-play situations (McGuckian, Cole, & Pepping, 2018).

Hence, the present dissertation had one overall aim: to identify characteristics of the visual–perceptual processes of elite football players in their natural performance environment and ascertain how these processes relate to on-field performance and contextual variables. Furthermore, in order to reach the overall purpose of this doctoral dissertation, five additional questions were posed:

1. How does scanning relate to on-field attacking performance?

2. What characterizes scanning behavior in different contexts and playing situations?
3. What characterizes the timing of scanning and how does this relate to on-field performance?
4. What characterizes the duration of scanning and fixations in elite football midfield players?
5. What characterizes the location and information (i.e., number of teammates and opponents) of scanning and fixations in elite football midfield players?

6.1. How to Define Scanning

As a combined consequence of acquiring new empirical knowledge and differences in research design (e.g., exclusively examining scans in attack vs. examining scans in both attack and defence), the concept of scanning has different operationalizations in the research literature as well as in the present dissertation. What is important to emphasize in this respect is that our operationalization of a scan, derived from the earliest definition by Jordet (2005), always involves looking for one or more of the following areas of interest: (a) teammates, (b) opponents, (c) space, (d) the referee, (e) pitch markings, and (f) the goals. Furthermore, in order for an exploratory head movement to be categorized as a scan, it needs to involve the intention of acquiring information from the game itself. Hence, a head movement away from the ball to talk to the coach or to look for a family member in the stands would not be measured as a scan. That is also why automatic scan measurement, for instance, by using a computer program or an IMU (e.g., McGuckian, Beavan, et al., 2020), must be supplemented by manual contextual interpretation in order to produce accurate measurements. To further elaborate on the conceptualization of scanning, I argue that scans are conducted relative to the development of play.

6.2. Scanning and On-Field Attacking Performance

It has been suggested that scanning can be divided into (a) head movements for action orientation (scanning to see what options are available in the environment, such as the location of the ball and the open space) and (b) head movements for action specification (scanning to guide a specific action, such as where to pass the ball) (van Andel, McGuckian, Chalkley, Cole, & Pepping, 2019). While most of the scans examined in this dissertation should be classified as action orientation scans, there is no way to determine the exact point at which players go from exploring for orientation to exploring for action specification. One hypothesis would be that this exploratory purpose alters as the ball travels toward a player (pass). In that moment, the scanning intention changes from exploring where the ball could come from (action orientation) to exploring the player's subsequent action possibilities once he or she receives the ball (action specification). For instance, the player might ask him- or herself, "Do I have the space to take a forward touch?" "Should I pass the ball on my first touch?" "Do I need to keep the ball in order for teammates to get in the right position?"

Interestingly, in Paper II, we found that elite youth players had a more forward-directed body position in the receiving moment when they were able to conduct their last scan closer to the moment of receiving. This supports the notion that the last scan conducted by players before receiving a pass should be categorized as an exploration for action specification (van Andel et al., 2019). Additionally, we found that U19 players were able to conduct their last scan significantly closer to the moment they received a pass compared to U17 players. Combined, these results suggest that the ability to conduct the last scan as close in time to the receiving moment as possible is related to the football performance of elite youth players.

In Papers I and II, the results showed that the average scan frequencies of players are positively related to their overall passing performance (whether or not a pass hits the intended target). These results substantiate previous findings in the literature on overall passing performance (Phatak & Gruber, 2019) and forward passing performance (Jordet et al., 2013). This suggests that players should strive to scan with high frequencies if their aim is to increase the level of their passing play. These results are supported by the theory of affordances, which emphasizes that the exploration of the environment allows for more opportunities for action for the perceiver (Gibson, 1979; Reed, 1996). Informed by this theory, each scan performed by a player would, presumably, either open up or close opportunities for passing (e.g., the player sees a teammate starting a run into open space vs. the player sees that a teammate who was free one second ago is now closely marked).

Moreover, high scan frequencies mean that players are able to have a constantly updated view of their surroundings and thus are not limited to only a few action opportunities (affordances) at the moment they get the ball. For instance, a player who scans five times in the 10 seconds before receiving the ball would be able to make continual adjustments to his or her movements and body positioning when receiving the ball based on the affordances that the environment now offers, which should result in a more optimal pitch position and body position for conducting future actions. In contrast, a player who scans only three times in the same 10 seconds can also make movement adjustments. However, these adjustments are informed by neither complete (information is not gathered in all important directions) nor updated information (the last scan was not conducted close enough to the ball receiving moment), meaning that the player has less of a chance to be in an optimal body position in an optimal space, which could result in a suboptimal action solution when they get the ball.

In Paper II, higher scan frequencies were found in situations where the players were able to receive in a forward or sideways body position compared to a backward body position. Similarly, we found that the timing of the last scan also influenced the receiving body position of the players: the players conducted their last scan significantly closer to the receiving moment in situations where they received the ball in a forward body position compared to a sideways or backward body position. These results reinforce just how important scanning is for football performance. A player who is able to receive a pass in a forward-directed body position is able to attack his or her opponents' goal or defensive lines immediately and is, therefore, much more "dangerous" than a player who receives the ball in a backward or sideways body position.

It is plausible that when players scan closer to the receiving moment, they get a more updated view of their surroundings, which in turn leads them to be more confident and positive in their decision-making with the ball. Equally, in accordance with affordance theory (e.g., Reed, 1996), their later scan timing also means that they will somewhat accurately know the position of their nearest opponent when they receive the ball, which means that they may more often encounter an environment that "affords" them the opportunity to attack forward. Conversely, when a player is not able to scan close to the receiving moment, he or she does, most likely, not know how close the nearest opponent is or how fast he or she is approaching. The player, therefore, is not attuned to the affordance of attacking forward and instead chooses the more careful solution of protecting the ball when receiving (sideways and backward).

6.3. Scanning in Different Contexts and Playing Situations

Playing position, pitch position, and playing phase have previously been found to be a constraint on players' head turning in match play (McGuckian, Cole, et al., 2020). In Papers I–III, we examined different ways in which scanning behavior (i.e., duration, frequency, and information) changed as a result of different contexts and playing situations.

First, we found that there were significant differences between scan frequencies in different playing positions (Papers I and II). More specifically, we found the exact same scan frequency ranking of player positions in both our studies on EPL players (Paper I) and U19/U17 youth elite players (Paper II): (1) central midfielders, (2) central defenders, (3) wingers, (4) full backs, and (5) strikers. Combined, these results suggest that scanning demands in different positions are somewhat constant from the later youth years and throughout the senior career years of footballers at the highest levels. These results are highly linked to our results on pitch area, showing that players scan regressively less as they (a) move closer to the opponent's goal line and (b) position themselves in the outer corridors instead of centrally (Papers I and II).

These findings contrast with previous results reported in the literature on head turning frequencies showing that players moved their head most frequently when they were positioned on the right side of the pitch (vertically) and in either the first or final third of the pitch (horizontally) (McGuckian, Cole, et al., 2020). There are a few possible explanations of these discrepancies. First, the measuring of head turns and scanning is methodically different, as head turns are measured irrespective of the ball, while scanning is always measured from the position of the ball. These contradictory results show that the definition of an exploratory head turn used in McGuckian et al.'s studies (e.g., McGuckian, Cole, et al., 2020), although similar, does not measure the concept of scanning first proposed by Jordet (2005). This distinction should be highlighted, as it affects both the research design and the interpretation of the findings. Second, while our results originated from attacking situations exclusively, McGuckian, Cole, et al.'s (2020) results originated from both attack and defence. Third, in accordance with Jordet (2005), in Papers I and II, we only measured scanning when the investigated player did not have possession of the ball (i.e., in the 10 seconds before receiving the ball). Contrastingly, McGuckian, Cole, et al. (2020) also measured head movements when the player was in possession of the ball. This last point is important to elaborate on further: per our definition, a scan always involves looking at the ball as the starting point. Hence, measuring scans while in possession of the ball would be methodologically problematic, since low scan frequencies while in possession would actually be preferred (this would probably mean that the player is looking for information away from the ball during the entire possession). For example, a player who receives the ball while looking in the direction of the goal, continues looking toward the goal until he decides to shoot, and then looks down at the ball when he decides to shoot would, per our definition of a scan, not conduct any scans in that situation. However, the player would conduct at least one head turn in the same possession (e.g., McGuckian, Cole, Jordet, et al., 2018).

Second, we found that tighter opponent pressure when receiving the ball had a negative influence on scan frequency. In Paper I, the players were found to scan significantly less when the opponents were 0–1 and 2 meters away compared to all other groups of opponent pressure distance (3 m, 4 m, 5–6 m, 7–9 m, 10+ m) when they received a pass. Similarly, in Paper II, we found that players had a significantly lower scan frequency when receiving the ball under tight pressure (0–3 m) compared to loose pressure (7–9 m) and no pressure (10–32 m). This concurs well with the results of Eldridge et al. (2013), who found that youth players scanned less in situations with tighter pressure. Additionally, these results somewhat explain why the strikers in our studies (Papers I and II), who are often tightly marked, had a comparably low scan frequency to the other playing positions.

As illustrated in Papers I and II, scan frequencies become lower as the play moves further and further toward the opponents' goal line. The tightest average opponent pressure distance can be found in the two central areas in the last fourth of the pitch (zones 14 and 15, Paper II). Naturally, these are areas where the strikers are most often the recipients of a pass. According to the ecological theory of perception, in cases with a lot of information, an individual will turn their attention toward the most important information to achieve their goal (McMorris, 2004). The main goal for attacking players in and around the penalty area is to either (a) score, (b) assist, or (c) assist the assist (Davies, 2016). The most important information in football is the ball (over 70% of all fixations in a game were conducted on the ball; Paper IV). Hence, when facing tight opponent pressure, players may be "scared" to look away from the ball, as this would temporarily make them lose sight of the most important information they require (the ball) in order to achieve their goal (i.e., scoring), which could result in them losing the ball to their opponent.

6.4. The Timing of Scanning and How It Relates to Performance

As previously mentioned in section 6.2, the results from Paper II revealed that the ability to conduct the last scan closer in time to the ball-receiving moment was associated with a more forward-oriented body position when receiving the ball. Interestingly, the results also showed that, on average, U19 players initiated their last scan significantly closer to the ball-receiving moment than U17 players (1.59 s v 1.92 s). Following the results from Paper III, showing that an average scan lasted 39.65 centiseconds (0.40 s), we find that U17 players, on average, have (1.92 – 0.40) = 1.52 s to prepare to receive the ball after their last scan, while U19 players only have (1.59 – 0.40) = 1.19 s to prepare. One possible conclusion based on this result is that U19 players need to update their information even closer to the moment they receive the ball because of the higher tempo-spatial demands inherent in U19 games (Rábano-Muñoz, Asian-Clemente, Sáez de Villarreal, Nayler, & Requena, 2019).

Moreover, this skill has probably been adapted through an ever-increasing tempo demand of the game during players' youth years through self-organization processes (Renshaw et al., 2019). As players get older and their playing level increases, they gradually encounter situations with less time and space than before. While they are still performing the same skill as before, they are now constrained to explore their environment closer to the ball-receiving moment in order to effectively perform their skill (i.e., receiving). Thus, learning becomes a process in which the players' behavior becomes more adapted and functional to the specific requirements of the performance environment (Renshaw et al., 2019). Jacobs and Michaels (2007) proposed the term "direct learning" to explain how an individual's learning is specific to the properties of ambient arrays in the environment and does not require inferential cognitive processing. Consequently, through direct learning, football players learn in a unpredictable performance context to vary their actions based on information that emerges on the pitch at all times (Renshaw et al., 2019).

6.5. The Duration of Scanning and Fixations

This dissertation includes the first studies to investigate the duration of scanning (Paper III) and fixations (Paper IV) in 11 v 11 football match play. In Paper

III, we found that 90.3% of all scans lasted between 2 (0.02 s) and 66 cs (0.66 s), with the most common scanning duration being 26 cs (0.26 s). In Paper IV, we found that the average fixation duration was 242.29 ms (0.24 s). Moreover, in Paper III, we found that only 2.3% of scans included a fixation and that these scans were significantly longer in duration than scans that did not include a fixation. Furthermore, we wanted to investigate whether different contexts (i.e., playing phase, player-to-ball distance) influenced the duration of the scanning and fixations of the players.

The playing phase did not impact scanning duration (Paper III) or fixation duration (Paper IV). These results may be explained by the fact that players use other contextual information to alter their gaze behavior and information gathering. Player-to-ball distance was measured as either near (0–24 m) or far (≥ 25 m) in Papers III and IV. We found no significant differences between scanning duration in the two distance conditions (Paper III). However, the players conducted significantly longer fixations in the far condition (266.63 ms) compared to the near condition (228.55 ms). This finding contradicts Roca et al.'s (2013) findings, which showed that both skilled and less skilled players perform longer fixations in the near condition than in the far condition when looking at a simulated football match on a screen. Furthermore, although we used the same fixation threshold (120 ms) and the same distance classifications, the mean duration of fixations in Roca et al.'s (2013) laboratory study was up to four times longer than the duration found in our real-world study. This substantial difference in results implies that laboratory studies, in which players are positioned sturdily in front of a screen, are less able to capture the visual reality that players experience during an actual game situation. This result supports the notion that perceptual-cognitive skills need to be examined in athletes' actual performance environment (Kredel et al., 2017) and questions the ecological validity of inferences drawn from studies that reduce the dynamic complexities of match play.

With regard to scanning duration, additional contextual variables on ball context were found to have a significant impact (Paper III). First, we found that players performed significantly longer scans when they initiated the scan while the ball was on its path from one player to another (during pass) than when the ball was in possession of another player. Second, players scanned for significantly longer durations when they initiated the scan while the ball was in the air compared to when the ball was on the ground. Both of these results suggest that elite players scan for a longer duration when they are better able to anticipate where the ball will be in the next few seconds. When players see a pass being played, they are able to anticipate approximately where the ball is heading. This principle is even stronger for passes in the air, where there are no obstacles (i.e., players) to prevent the ball from getting to the anticipated destination. These results are both in accordance with the principles of tau theory, which states that if you observe an object's speed, angle, and distance at a specific moment in time, you can accurately predict where and when the object will arrive without the need to follow its path visually (Lee, 1998). In contrast, when players initiate their scan when another player has possession of the ball, they are not able to anticipate where the ball is when they return their head and eyes back toward the ball, as they do not gather any information from the object (i.e., the ball) before they scan for information elsewhere. Hence, in these instances, players will naturally conduct shorter scans in order to avoid missing important information about the ball.

6.6. The Location and Information of Scanning and Fixations

With regard to what the players who participated in Papers III and IV looked at, this dissertation is the first to investigate the locations/areas of interest of fixations

(Paper IV), as well as the number of teammates and opponents found during scanning (Paper III), during real football match play. In Paper IV, we examined how many areas of interest (ball, teammate, opponent, space) players looked at during their fixations. The results showed that the players fixated most on two areas of interest, followed by three, one, and zero areas (only space) of interest. This effect was stronger in defense than in attack.

No previous studies have classified areas of interest in this way. Instead, all previous studies in laboratories have only exclusively measured one area of interest for each fixation (e.g., Vater et al., 2016). Thus, the abovementioned results, showing that players often fixate on multiple areas of interest, are indicative of the possible methodological limitations of analyzing the gaze behavior of football players by having them look at a screen. When doing so, participants are not looking at areas of interest at the same distances as they would during a match in which multiple areas of interest might be a part of their fixations. Instead, they exclusively look at a projected image 3 m (Roca et al., 2018) or 2.8 m (Vater et al., 2016) away, distances in which researchers would be unable to measure more than one area of interest as part of their fixations (e.g., Roca et al., 2013). Hence, the results described above, more than any other findings in this dissertation, show the need for eye-tracking studies to be conducted in athletes' actual performance environment (Kredel et al., 2017).

Nonetheless, our results build upon those of experimental studies on gaze behavior in which the experimental tasks are representative of the performance context (e.g., Williams et al., 1994). Given that our observations were based only on foveal fixations, our results do not necessarily indicate that the players' attention is focused on the same location (Hüttermann et al., 2018). Therefore, although there is a strong correlation between gaze direction and attention allocation (Holmqvist et al., 2011), the results from the eye-tracking device should not be mistaken for a direct measure of attention at any given moment (van Maarseveen, Savelsbergh, & Oudejans, 2017). For instance, a player could deceive his or her opponent by disguising his or her intention by looking in one direction while focusing on another area. One obvious situation in football would be a striker who is through on goal in a 1 v 1 situation with the keeper. He or she might intentionally mislead the keeper by foveally fixating on one side of the goal while having the attention and intention to finish in the other side of the goal. Furthermore, in instances where the player's attention differs from the point of fixation, it is reasonable to assume that information processing occurs in the player's peripheral vision and is processed through different neurological pathways (Hüttermann, Ford, Williams, Varga, & Smeeton, 2019). Such viewing strategies have been referred to as "gaze anchors" and "visual pivots" (Vater et al., 2019).

With regard to scanning information, the descriptive results from Paper III show that midfield players most often had (a) zero teammates and zero opponents inside the video frame during their movement phases of the scan, (b) two teammates and one opponent inside the video frame during the stop point of the scan, and (c) zero teammates and zero opponents inside the foveal circle during the stop point of the scan. A possible explanation for the relatively small number of players found most frequently in the different parts of the scans might have to do with *why* a player was scanning. It is likely that players often scan because they want to locate open space around them (objectless information), which they can exploit either by moving into that space or by playing the ball into it when they receive it, rather than looking for teammates and opponents (information from objects). An example of an often-occurring scan, based on the results above, could be a situation in which a player makes a small head movement (so that the ball is no longer in his peripheral vision) to see if his teammate has control of his direct opponent. Since the head movement is relatively small, no other players become visible between the moment when the player looks at the ball and the moment when the player stops his scan. At the stop point of the scan, the player peripherally notices the positions of the players but focuses his attention on the space between these players before once more returning his head and eyes towards the ball.

Additionally, we examined whether the number of opponents and teammates found during the different parts of the scans changed as a result of (a) player-to-ball distance or (b) playing phase. For the movement phases, the results showed that (1) more players were found in attack compared to defense, and (2) more opponents than teammates were found in attack. Similar results, showing that more opponents than teammates were found inside the players' video frame in attack, were also found at the stop point of the scan. For the foveal circle stop point, again, the results showed more opponents than teammates. However, in contrast to what was found in the movement phases, more players were found in defense than in attack. Surprisingly, different player-to-ball distances did not influence the number of teammates and opponents located within the scans of the players in either part of the scan. It should be noted that this method of using eye-tracking technology to measure information during scanning in 11 v 11 match play has never previously been conducted. These results, therefore, need to be interpreted with caution.

Lastly, with regard to the exact location of fixations, we found that players had the highest percentage viewing time on the PiP (ball and opponent) in defense and on the ball, opponent, teammate (B/O/T) category in attack (Paper IV). The results in defense mirror those of previous studies that have examined fixations in match-like defensive scenarios in laboratory settings (Roca et al., 2013; Vater et al., 2016). This is salient because it implies that fixation location results that originate on the field can be somewhat reproduced in laboratory research designs if the conditions are very similar (11 v 11 defense).

6.7. Limitations

It is plausible that a number of limitations may have influenced the results obtained in this dissertation (see the different papers summarized in the previous sections for detailed information). These limitations underline the difficulty of collecting data in uncontrolled settings, such as an actual non-restricted football match, with technology that has not previously been used in such a manner. First, eye-tracking equipment has never before been used in an actual elite-level football match. Hence, the data obtained using this technology in an uncontrollable environment (Papers III and IV) includes a major source of uncertainty. Second, although we conducted an extensive reliability analysis, human error is an inherent feature of the manual coding of scanning used in Papers I–III. Third, the limited and heterogeneous sample size in Papers III and IV means that caution must be applied, as the findings may not be transferable to other playing positions or players with lower skill levels. Fourth, the research presented in Papers III and IV was not specifically designed to evaluate factors related to performance or decision-making. Consequently, no causal explanations for how scanning and gaze behavior influence on-field behavior can be drawn from these studies.

6.8. Theoretical and Methodological Implications

The inferences drawn from the current dissertation can be explained using the ecological approach to visual perception. In ecological psychology, it is widely accepted that an individual's intention drives the focus of his or her perceptual systems (Jacobs & Michaels, 2007). At the highest order, the intention of a football player, as well as players in other invasion games, is to create and exploit opportunities for goal scoring in the attack phase and to regain possession and prevent goals against his or her team in the defense phase (Ronglan, 2016). Thus, it is reasonable to assume that the players who participated in the studies included in this dissertation fixated on and scanned for objects and space relevant to the individual and team's attack and defense strategy (playing style) as well as sociocultural constraints (Vaughan, Mallett, Davids, Potrac, & López-Felip, 2019). Moreover, the results presented in this dissertation (e.g., that players who scan closer to the ball receiving moment is receiving the ball in a more forward-oriented body position) support the notion that perception and action are closely intertwined and specific to the performance context and act as a basis for understanding decision-making and skill execution in a holistic, emergent, and continuously evolving process (Correia, Araujo, Cummins, & Craig, 2012).

According to Gibson (1979), what we perceive regulates our actions, and our actions allow for information to be perceived, which provides the opportunity for constant movement adaptations. Perceptual learning, according to this approach, constitutes an increased ability to extract previously unused information from the environment, which occurs as the result of an increased ability to differentiate between the available information (Gibson & Gibson, 1955). It is clear that the players in Papers I and II learned to perform actions that inform behavior (scanning), which in turn led to adaptive behaviors (e.g., specific body positioning when receiving), resulting in different emerging affordances in the environment for the players (e.g., forward body position could lead to the emergence of space to dribble in) (Reed, 1996). Moreover, as all behaviors, per this perspective, are deemed perception–action behaviors, we should interpret each scan and each fixation as clear quantifiable indications that visual–perceptual processing are taking place when playing football, without the need to refer to the sensory inputs and the neural interactions of the players.

Following this, as the results from Papers I, II, and III show that scanning is a widely used visual perceptual technique in elite level football players across all playing positions (Papers I and II), there is reason to believe that studies in which participants look exclusively at a screen in front of them with no need to scan their surroundings (e.g., Cañal-Bruland et al., 2011) are unable to capture the normal visual perceptual behaviors that football players use in actual match play. Recently, the first attempt to use immersive curved screens in football laboratory research was made (Hüttermann et al., 2019). This design has the potential to make laboratory research more representative of performance contexts. Unfortunately, the researchers in that particular study chose to use pictures of player figures instead of video footage, thus limiting the representativeness of the study. In fact, although laboratory experiments in this research area have attempted to bridge the gap between laboratory and field by including motor responses (e.g., Savelsbergh et al., 2010) and immersive screens (i.e., Hüttermann et al., 2019), the question of whether it is possible for a laboratory to create the same visual–perceptual reality that football players encounter during competition remains to be seen. It is difficult, for example, to simulate task constraints such as opponent pressure (Pinder, Headrick, & Oudejans, 2015), environmental constraints such as weather conditions (Renshaw et al., 2019), and emotional constraints such as risk-taking (Headrick, Renshaw, Davids, Pinder, & Araújo, 2015) in a laboratory setting. Furthermore, although research has shown that anxiety levels affect football players' visual search strategies (Vater et al., 2016), it is essentially impossible for researchers to design an experiment that includes such emotional factors. Hence, as previous researchers have argued (e.g., Dicks, Button, & Davids, 2010; Klostermann & Moeinirad, 2020), research on visual perception in football has to be conducted in the football players' real performance context (during 11 v 11 match play) in order to accurately capture the scanning and fixation strategies that together constitute players' visual perception in football.

6.9. Practical Implications

Given that the current dissertation has focused on elite players, the findings are particularly relevant for guiding player development in football. For example, our findings suggest that focusing (foveally fixating) on the PiP (the ball carrier and the ball) may be a relevant gaze behavior for younger and less skilled players. Studies on Australian-rules football players (Lorains, Panchuk, Ball, & Macmahon, 2014) and handball players (Florkiewicz, Fogtman, Lesiakowski, & Zwierko, 2015) have shown that a video-based training intervention can change athletes' visual search strategies. However, such strategies should be viewed with caution, as the extent to which video-based and virtual reality-based training are representative (inducing the same dynamics in the players' use of their visual–perceptual systems compared to real-world match play) remains unclear. Similarly, empirical research in football has shown that training can increase players' scan rates, although it is unclear whether increased scan rates as a result of off-pitch training interventions can improve on-pitch performance with the ball (Jordet, 2005; Pocock et al., 2017). Nevertheless, by exploring how elite players use their vision in match play, researchers and practitioners may be able to design training situations to help players develop the same level of visual expertise.

Furthermore, the results of this dissertation illustrate the need for training to replicate the game of football, as they reveal that (a) scanning information, (b) scanning duration, (c) fixation duration, and (d) fixation location all change as a result of football-specific contexts, such as attack vs defense, distance to the ball, playing position, ball context and action undertaken with the ball, and pitch position. Only by training in settings similar to the performance environment can players learn to adapt to the visual reality and affordances that the game offers. Practically, this means that the training has to (1) involve more areas of interest (ball, opponent, and teammate) (Paper IV); (2) be position specific (Papers I-IV); (3) include both attacking and defensive playing phases (Papers III and IV); and (4) be played on a big enough surface to allow for the perception of information in both near and far distances (Papers III and IV). There is no other way to ensure that the visual–perceptual reality of footballers is met during training. However, if coaches choose to ignore this and instead focus their training on non-contextual exercises, such as (a) ball-possession games without goals and direction in small areas (often referred to as *rondos* by coaches), (b) passing drills where you are told to play from A to B, or (c) shadow play (without opponents), then the players will probably not learn to use their perception to inform their decision-making and execution in representative performance settings, which is paramount if they want to reach the highest levels.

In their book *Youth Development in Football*, Nesti and Sulley (2015) present findings on how eight elite academies are organized on every level. They found that all academies focus on in-game technical skills instead of isolated technical skills, and that coaches are adamant that technique and decision-making should be trained in a real-world environment (Nesti & Sulley, 2015). The results of this dissertation support this practice. However, it can be speculated that most coaches and most practice environments are still too much in love with *rondos*. These exercises became extremely popular in the 2000s, when they were seen as one of the main reasons why Barcelona and Spain were able to play their new possession-oriented dominative style. Consequently, I find myself almost never watching a practice without witnessing some sort of *rondo*, such as a 4 v 2 exercise on a 10 × 10-m pitch. The issue with this type of exercise is that it requires no scanning. There is no need for players to scan, as they always have all their teammates and opponents inside their field of vision. In fact, one could argue that each pass conducted in such an exercise is performed in a different way than you would during a match, where almost every ball reception and pass are preceded by at least one scan. Hence, based on the results of this dissertation, relying on data collected from actual gaze behavior and visual perception in 11 v 11 football matches, I strongly recommend that coaches find other more representative exercises in which actions like passing and receiving are performed in a visual–perceptual reality similar to the game itself.

Another practical implication proposed in this dissertation comes from the finding that only 2.3% of scans involved fixations (Paper III) and that over 90% of scans lasted 0.66 seconds or less. This result could have major implications for how coaches choose to implement scanning training. Coaches need to create training scenarios in which players are “forced” to scan often without having to fixate on an object while scanning. I know from personal experience that coaches often ask players to scan for items, such as written numbers and words or a certain number of fingers held up in the air, during a variety of different drills. These tasks require players to fixate during their scans in order to see a high-definition picture (Duchowski, 2007). Instead coaches should design exercises in which the players scan for colors, movement, and space and where they are forced to conduct rapid scans in order to keep track of the ball.

Lastly, the combined results of Papers II and III suggest that there might be an optimal strategy for scanning in football. In instances where players are able to gather information about where the ball is going to be in the near future by, for example, detecting the trajectory and speed of a pass, players can use this time period to scan their surroundings for important information away from the ball without losing track of the ball. In contrast, when players have yet to receive useable information about the ball, they need to look at the ball until an action is undertaken that informs them where the ball is going to be/end up in the near future (e.g., a dribbling touch, a receiving touch, a pass). Together, these findings suggest that the optimal scanning strategy for any player is (1) to look at the ball every time it is touched, (2) to scan for information away from the ball immediately after each receiving and dribbling touch, and (3) to scan for information away from the ball frequently and as close to a receiving touch as possible during passes. It is a dream of mine to see an entire team turning their heads at the same time, according to these three principles. In doing so, this team will, in my opinion, have a competitive advantage over teams with a less informed visual–perceptual strategy.

6.10. Future Research

Lastly, this dissertation emphasizes how crucial it is for future research on football players' visual perception to be conducted on the football pitch in competitive settings instead of inside the laboratory, or in decontextualized in situ settings (e.g., microstates of play). Future researchers should utilize the methods used in this dissertation (video analysis and eye tracking) to expand our knowledge of how different aspects of visual perception and gaze behavior vary across different playing positions, genders, age groups, and skill levels. Research using the expertise approach (comparing experts and novices) across different sports has provided extensive evidence that experts are better than novices at picking up cues of event outcomes because they fixate longer on movements that occur earlier in the kinematic chain (e.g., a keeper looking at the non-kicking leg of a penalty-taker) (Abernethy, Farrow, Gorman, & Mann, 2012). Unfortunately, comparing the gaze behavior results of elite players to those of less skilled players was beyond the scope of this dissertation. Further research should attempt to use the expertise approach in non-restrictive designs similar to those used in Papers III and IV in this dissertation. This could build upon the extant evidence on gaze behavior that has come solely from laboratory research.

Furthermore, future researchers should try to implement an intervention experiment on scanning training in actual football settings. As a growing body of evidence now suggests that scan frequency and timing are prerequisites for football performance, it would be interesting to see whether a group of players could increase their match scan frequency through focused training in representative settings. Additionally, if researchers choose to build on the original research on gaze behavior in non-restrictive settings, as was attempted in this dissertation, they should aim to include a mixed-method design in which they include qualitative reports from the players themselves as well as their coaches. This approach could potentially expand our understanding of why players look and scan the way they do, how their “seeing” impacts their decision-making and performance, and if these behaviors are conscious or subconscious in nature.

6.11. Conclusions

This doctoral dissertation aimed to identify characteristics of the visual–perceptual processes of elite football players in their natural performance environment and ascertain how these processes relate to on-field performance. To achieve this aim, five research questions were formed and addressed through the use of different research methods (i.e., video analysis and eye tracking) and statistical methods (i.e., analysis of variance and Bayesian model) across four papers. To summarize the main findings, Papers I and II showed that scan frequencies alter as a function of positional (i.e., playing position and pitch position) and contextual (i.e., opponent pressure) factors and that there is a positive relationship between scan frequency and pass completion. In addition, Paper II showed that U19 players had higher scan frequencies and better scan timing compared to U17 players, and that players who performed their last scan closer to the ball receiving moment were able to receive the ball in a more forward-oriented body position. In Paper III, the results revealed that the duration of scans was influenced by the context of the ball and the action undertaken with the ball when the scan was initiated. Furthermore, the results showed that only 2.3% of scans included a fixation, suggesting that players are able to gather the required information without the need to foveally fixate surrounding objects and spaces when scanning. In Paper 4, differences in fixation duration and location were found in attack vs defense and in near vs far player-to-ball distance conditions. Moreover, fixation durations were far lower than reported in previous laboratory studies.

Taken together, the findings presented in this doctoral dissertation suggest that scanning is an integral and essential part of performance in elite football. Additionally, the results provide novel information on the visual search strategies of football players during actual football match play. Furthermore, this dissertation emphasizes the need for more research to be conducted in non-restrictive competitive settings in order to ensure that the empirical evidence on visual perception and gaze behavior—which has the potential to inform future research designs and coaching practices—resembles the visual–perceptual reality that athletes encounter in competition.

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Paper I

Jordet, G., Aksum, K.M., Pedersen, D.N., Walvekar, A., Trivedi, A., McCall, A., Ivarsson, A. & Priestley, D. (2020). Scanning, contextual factors, and association with performance in English Premier League Footballers: An investigation across a season.

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Scanning, Contextual Factors, and Association With Performance in English Premier League Footballers: An Investigation Across a Season

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Scanning in football (soccer) denotes an active head movement where a player's face is temporarily directed away from the ball to gather information in preparation for subsequently engaging with the ball. The aim of this study was to learn more about the ways that 27 elite professional football players in an English Premier League club use scanning in competitive matches, the conditions under which this behavior is exhibited, and the relationships between these behaviors and performance. Players were filmed across 21 matches, producing a total number of 9,574 individual ball possessions for analysis. Close-up video analyses of scanning show positional differences (with central midfielders and central defenders scanning most frequently, forwards least) and contextual differences (with relatively lower scanning frequency in situations with tight opponent pressure, in positions wide in the field and closer to the opponent's goal, and under certain game state conditions). Players scan more frequently prior to giving passes than when they dribble, shoot, or only receive it, as well as prior to more long/forward passes compared to short/backward ones, although these differences are small. A Bayesian hierarchical model, which accounts for individual player differences and pass difficulty, suggests that the more a player scans, the higher the probability of completing a pass. In conclusion, match demands are likely to constrain the extent to which highly elite players scan, and scanning seems to have a small, but positive role in elite football players' performance.

Keywords: soccer (football), perception, decision making, vision, visual search, exploration

INTRODUCTION

Football (soccer) is a highly dynamic, fluid, and complex sport, and players' ability to pick up and use visual information from teammates and opponents may, logically, be a key to performance. Indeed, researchers have uncovered perceptual and cognitive mechanisms that differentiate skilled from less skilled football players, and superior from inferior performances (for recent reviews, see Mann et al., 2019; Williams and Jackson, 2019). Much of this research has, however, examined visual search strategies. Typically, these studies are carried out with eye tracking devices where players view and respond to photographs or video films positioned in front of them in a laboratory setting. Some of these studies reveal that skilled football players fixate their gaze less frequently, but with longer durations, which may imply that they are able to extract more information from each individual visual fixation (Helsen and Starkes, 1999; Cañal-Bruland et al., 2011). Other studies show that skilled football players fixate their gaze on the displayed information more frequently, but with shorter duration (Vaeyens et al., 2007a,b; Roca et al., 2011). Recently, for example, in a study of 44 professional and semiprofessional players in England (Roca et al., 2018), the most creative players adopted a broader attention span, by showing more visual fixations of shorter duration than the less creative players. This frequent change in fixation location makes sense as, in team ball sports, players are required to shift attention between different objects, most notably between the ball and other players (Jordet, 2005a,b; Mann et al., 2019). With that said, all these studies have been conducted in laboratories, and it is possible that variations in the extent to which the experimental setup resembles the real world (i.e., the degree of representative design, see Araújo et al., 2007; Pinder et al., 2011) could account for the different results. Indeed, a substantial gap in the literature on perceptual and cognitive processes in sport is the lack of research focusing on what athletes are doing on the field in real competitive events (outside the laboratory).

In addition, very few studies have documented perceptual processes of truly elite, professional players, possibly because this population is difficult to recruit for this type of research. Thus, another line of research has started from the other direction than the laboratory visual search studies, by systematically observing and analyzing elite football players' behaviors in actual, real-world games. This relatively new paradigm is based upon the ecological theories by Gibson (1966, 1979), who argued that perception is an active process of obtaining information from the world, a psychosomatic act, consisting of motor action. Exploratory activity is activity initiated to detect information (Gibson, 1966, 1979). More specifically, exploratory activity denotes "the scanning for and use of information [that] involves adjustment of the head and sensory organs to the ambient energy fields" (Reed, 1996, p. 80). In football, this activity is sometimes referred to using other terms. For example, in German football, they use the word "vororientierung" (e.g., Scheibe, 2019), which translated to English would be "pre-orientation" (specifying that this activity takes place prior to receiving the ball). In English, coaches often refer to this activity as "checking your shoulder" or "scanning." With respect to empirical research on this activity, Jordet (2005a) was first to film professional football players with high-zoom video cameras to obtain close-up images of each individual player, making it possible to examine details in the players' scanning behavior leading up to receiving the ball. It was shown that for midfielders, engaging in successive scanning of the areas of the field behind one's back seemed a necessary foundation to subsequently perceive and successfully act upon information located in these areas. In the most extensive research report to date, Jordet et al. (2013) obtained and analyzed Sky Sport's PlayerCam broadcasts of 1,279 game situations with 118 football players (midfielders and forwards) in the English Premier League (EPL). The players in this sample who at some point had received a prestigious individual award (e.g., FIFA World Player of the Year) scanned more frequently than others prior to receiving the ball, and there was a positive relationship between scanning frequency and pass completion. Similarly, in a study of three youth elite, midfield players, it was found that when the players showed any scanning behaviors prior to receiving the ball (compared to the ones who did not show any such behavior), they performed more forward passes, executed more passes into the attacking half, performed more turns when opportunities arose, and experienced less defensive pressure from opponents (Eldridge et al., 2013). However, there was no significant relationship found between scanning and maintained possession of the ball.

Additionally, attempts have been made to analyze football players' head movements using wearable inertial measurement units, worn in a headband at the back of players' heads. Results show that higher scanning frequency before possession (i.e., measured as all registered head turns, thus not necessarily linked to directing one's face toward areas located away from the ball) is associated with faster passing response time (McGuckian et al., 2019) and higher likelihood of forward passes (McGuckian et al., 2018). However, there was no relationship with pass success in any of these studies. Further, higher head turn excursion (i.e., degrees of head turning) was associated with higher likelihood of turning with ball and switching play, whereas lower excursion was associated with higher likelihood of performing one-touch passes (McGuckian et al., 2018). Finally, it has been found that youth elite players scanned more extensively when in possession of the ball than without the ball, more in the back third of the pitch and least in the middle third of the pitch, and players in more central roles scanned more extensively than players in wider roles when they themselves, or their team, had possession of the ball (McGuckian et al., 2020).

However, none of these field-based studies have sufficiently controlled statistically for contextual and personal factors that may influence these results, and it seems paramount to examine the impact of such factors. One example of considerable contextual influence on scanning could be interpreted from a study comparing futsal and football players, where the scene camera of a mobile eye tracker was used to collect data on attention orientation during a 5-v-5 small-sided game setup (Oppici et al., 2017). It was found that the futsal players focused their attention toward other players during ball reception and control, whereas the football players scanned more toward other players when they were not involved with the ball (and their team was in possession of the ball).

To summarize, there is evidence for some contextual variation with respect to football players' visual scanning, and there seem to be some performance benefits of engaging in scanning prior to receiving the ball. However, there is still very limited knowledge about how elite, professional football players employ scanning behaviors in actual real-world games. Additionally, researchers have typically relied on a relatively small number of observations, using less robust statistical methods that do not account for contextual and personal variation. We expect that the use of more sophisticated statistical analyses better will reveal the relationships between scanning, situational context, and performance. Thus, the aim of this study was to learn about how elite professional football players use visual scanning in real games; establish the extent to which scanning varies under different contextual conditions (e.g., positional role, opponent pressure, pitch location, and game states); and to examine the relationships between scanning and performance. Within this scope, and following discussions with professional coaches at the club this study was carried out at, the main hypothesis that we wanted to test is: Scanning plays a role in successfully completing passes, when we sufficiently control for personal and contextual variation. In addition, following tendencies found in previous studies, we hypothesized that players in central positional roles and locations in the pitch would scan more than players in more peripheral roles and locations, that players under low opponent pressure would scan more than players under high opponent pressure and that scanning would be linked to more forward actions in the field.

MATERIALS AND METHODS

Data and Participants

Participants were 27 professional male football players aged 17–32 years (M = 25.66 ± 4.26). All players represented the same team in the EPL in the 2017/2018 season. The data consisted of individual player ball possessions registered in 21 home games (13 Premier League games, 6 UEFA Europa League games, and 2 League cup games) that we filmed that season. This totaled 9,574 ball possessions. The study was reviewed and approved by the Norwegian Centre for Research Data (NSD)—project number 57718. Written informed consent for participation was not required.

Procedures

The matches were video recorded with three 4K video cameras: two Blackmagic Micro Studio Camera 4K (frequency of up to 59.94 fps) and one Panasonic AG-UX90 4K Camcorder (frequency of up to 60 fps). All cameras were set up and operated by one of the co-authors at a designated camera platform, positioned up in the stands at the mid-point of the touchline. Each Blackmagic camera was fixed to cover one half of the pitch, while the Panasonic camera was manually panned from side to side to cover the ball and as many of the players on the pitch as possible. Following game completion, the video recordings were transferred onto portable hard drives.

We then merged the recordings of each of the two halves from the two Blackmagic cameras together using homography transformations and Opencv package in Python 3.6 and combined this recording with field location coordinates that were hand-tagged by match analysts working at the club using their proprietary software. We used these coordinates to create a Python program that automatically kept the targeted player in the middle of the screen, while zooming in on him to provide a close-up video recording of that player. For the coding of the behaviors on the videos, we created a web-based program using PHP and javascript. When the coders logged on to this program online, they first selected the game and player, and a list of the situations with that player in that game would appear. When they selected a situation, they would automatically see the close-up recording of that player at the left of their screen and an overview video recording of the game (from the Panasonic camera) at the right of the screen. Both these videos were synced at frame level, i.e., the coder could only play the videos together at the same rate. The program recorded keystrokes that were assigned to different variables along with the exact time in the video. In order to obtain the precise time, the user could also move the video forward/backward by one frame at a time. The program also allowed coders to correct their coding by undoing the previous step.

After permission was obtained from the club to film games, we conducted several tests of the filming procedure to first arrive at an effective way to capture such data, and second to ensure the quality of the video recordings. In total, prior to the actual data collection, two initial pilot games were filmed at another stadium and another five test games at the Premier League club stadium. Following this testing, we successfully filmed the remaining home games of the season (except three games, two in the Europa League, and one in the Carabao cup, played during the testing phase, early in the season, which were not prioritized at the time and hence not filmed). One additional game was filmed, but a technological error with one of the cameras precluded the analysis of this particular video recording. Generally, conducting a data collection of this magnitude at a Premier League club is a vast logistical undertaking. Space limitations make it difficult to describe every single aspect of our procedures here, but people interested in replicating our study or our methods are encouraged to contact the lead author who will be able to answer any questions about the procedures.

Manually coding behaviors from distance video recordings of a dynamic and complex real-world event (such as a football game) is unlikely to produce fully objective data, and it was important for us to strive for as much rigor as possible in these analyses. Ultimately, eight students manually coded the behavioral data coming from the videos. These coders comprised of five students in football coaching at the Norwegian School of Sports Sciences and three students from different American universities who all had in common that they attended the 2018 MIT Sloan Sport Analytics conference in Boston, MA. Everyone was trained in the procedures, where they coded a selection of situations and received feedback by an experienced coder. Only when their coding would yield a total agreement of at least 80% with one of the experienced coders on all tested variables (80% cutoff for coding of behavioral data has previously been used as an acceptable threshold in sport psychology, Hrycaiko and Martin, 1996) was the person allowed to code the data that would be used for further analysis. After the actual analyses had commenced, we continued to test the interrater reliability for all coders and on all behavioral variables. An experienced coder (who had completed a master's thesis on the topic of visual perception in football, had background as a professional football player and was also used to train the student coders) blindly coded a total of 784 randomly selected ball possessions previously coded by the eight coders. To assess the interrater reliability, we followed the recommendations from Hallgren (2012) and calculated Cohen κ for nominal variables and intraclass correlations (ICCs) for ordinal, interval, and ratio variables. For the primary variable in our study, scanning, we found the following ICC coefficients between each of the eight coders and the expert coder (in descending order): 0.993, 0.991, 0.988, 0.986, 0.982, 0.981, 0.937, and 0.825 [mean (M) = 0.960, standard deviation (SD) = 0.058]. Based on suggested cutoffs all these scores were considered excellent (Cicchetti, 1994). The coder who had considerably lower ICC values than the others (at 0.825) was followed up throughout with extra feedback and training. Although his ICC score could still be considered more than acceptable, we decided to stop his work (yet retain his coding for the analyses). Of all the coders, he was the one who coded the fewest ball possessions, with a total of 200 possessions coded. Also, in an early phase of the coding process, there was one more individual who passed the training phase and started coding, but whose personal ICC values were even lower, at 0.515 in total. Even though this value is considered "fair" (following Cicchetti, 1994), we decided to stop the work with this coder, cut all the possessions that had been coded by this individual (329 possessions in total), and have another coder recode those possessions. For the aggregated reliability results, see section *Interrater Reliability*.

Variables

There were three categories of variables in this study, those related to scanning, context, and performance with the ball.

Scanning

In ecological psychology literature (e.g., Gibson, 1979), "exploration," "exploratory behavior," or "exploratory activity" are the preferred terms, while in more cognitively oriented literature (e.g., Mann et al., 2019) "visual search" is more used. In this article, unless we are referring to specific theoretical or empirical work where sticking to their original term is of importance, we will refer to this activity as "scanning."

Scan

A scan was operationally defined as a player's active head movement where the face (and hence, the eyes) is temporarily directed away from the ball, with the assumed intention of gathering information about teammates and/or opponents, to prepare for subsequently engaging with the ball (based on Jordet, 2005b).

Scan frequency

Scan frequency is the number of scans per second, measured in the last 10 s that the team possessed the ball, before the target player received the ball. The 10-s cutoff has been used in previous studies on scanning in football players (e.g., Jordet et al., 2013; McGuckian et al., 2018). If within that 10-s time interval, the other team had possession and lost it to the target player's team, the time interval would instead start at the moment possession was won and end with the target player receiving the ball. Ball possession was here defined as having control of the ball. In instances where the opponent team was in contact with the ball one or two times without having control (typically when clearing the ball out, dueling for the ball, or deflecting a pass), the target player's team had not lost possession in our analyses. For set plays (e.g., a free kick or a throw-in) within the 10-s interval, the time interval for measuring scans was set from 2 s before the ball was put in play (to allow some time to register scanning prior to the ball is in actual play), and end when the target player would receive the ball.

Context

Positional role

The positional roles were categorized into central defender, side defender, central midfielder, winger, and forward. This categorization was based on the official line-up for each game (disclosed by the club) indicating the positions held by the players at the start of the game. This was then verified with the exact average x, y position on the pitch that each of the players was located at in each game (also publicly disclosed by the club, on their website). Thus, if a player changed position during the match, his involvement would still be coded in the playing position he had for the beginning and/or most of the match.

Pitch location

Pitch location is defined as the player's position on the pitch when receiving the ball from a pass. Pass distance is calculated as the difference between the location of a pass and its reception. The x, y coordinates of the pass event (and reception) were hand-tagged by the club's professionally trained coders (StatDNA LLC). Trained coders simultaneously view broadcast footage with a pitch map, and they tag onto the pitch the approximate x, y coordinates of a pass event and its reception using proprietary tagging software.

Optical tracking data (e.g., TRACAB®; Linke et al., 2020) could have provided a higher resolution alternative, but it was not available in our dataset. It is important to note that there is no ultimate "ground-truth" for positional data, because as yet there is no tracker inside the football (or universally worn by all players) to accurately measure their pitch position in real-game situations. As a result, there will always be some degree of measurement error, and here we relied upon a twofold quality assurance (QA) process in our data collection to attempt to mitigate this. First, automated tagging software detects and flags any unrealistic positional values (e.g., passes made that originate out-of-bounds and are not set pieces). This is followed by a QA evaluator rechecking the coded data to ensure reasonable values.

Opponent pressure

Opponent pressure was operationally defined as the distance between the target player and the closest opponent, at the moment the target player received the ball (measured in meters). This was visually assessed for each ball possession by the student coders. The coders were trained in using a variety of reference points to facilitate reliable assessments of these distances, such as the length and width of the pitch, the distances between different lines and markings on the pitch, and the width and length of the checkered/striped pattern in the grass on the pitch (all in exact meters).

Game state

We assessed game state in two basic ways: game standing and accumulated game time. Game standing denotes whether the team, at the moment of that particular ball possession, is winning (i.e., ahead in the stand, such as 1–0, 2–1 or 2–0), losing (i.e., behind in the stand, such as 0–1, 0–2 or 1–2), or drawing (i.e., the stand is tied, such as 0–0, 1–1 or 2–2). Accumulated game time was assessed using 5-min time intervals (from 0 to 90 min, including a category for added time to each half, so 45+ and 90+ min). To capture real accumulated game time for each player, only the players who started the game were included in this particular part of the analysis.

Performance With the Ball

Action direction

This variable assesses the direction of the target player's action in each situation, where the direction is estimated by the final position of the ball after the end action (as a player may move in several directions while being in possession of the ball) in relation to the opponent's goal line. Forward action is when the ball (e.g., from a pass or dribble) ends up closer to the opponent's goal line; backward action is when the ball ends up further from the opponent's goal line; sideward action is when the ball ends up approximately at the same distance from the opponent's goal line. Only vertical direction was measured in this variable, and possessions were only categorized as sideward in those instances where we could not say for sure that it was either forward or backward. The coders were trained in using the checkered/striped pattern in the grass on the pitch as a reference when assessing whether an action was forward/backward or sideward.

Action type

The types of last actions registered were pass, shot, dribble, and receiving (where the latter typically, but not always, would imply that the ball was lost in the act of receiving or attempting to receive). The types of passes registered were long penetrative pass (passing two or more lines of the opposition defense, where a line could be the forward line, midfield line, and defensive line), short penetrative pass (passing one line of defense), forward non-penetrative pass (forward in the field, but not passing any defensive line), sideward pass (neither forward nor backward), backward pass, and no-pass (where the last action registered was a shot, dribble, or receiving the ball).

Successful actions

If the team of the target player maintains possession after the player's last action with the ball, this is registered as a successful action (although we do not claim that this would be the right action in view of a coach). Typically, this is a pass that reaches a teammate (i.e., pass completion), but it could also be a shot that is scored or a dribble or receiving action that produces continued possession (via a deflection so the ball goes to a teammate or a won throw-in). If the ball goes to an opponent (e.g., a pass that is intercepted, a failed dribble, a shot that goes wide of the goal, or a failed attempt to receive the ball), thus possession is not maintained, it is registered as an unsuccessful action.

Statistical Analysis

Interrater Reliability

For number of scans (the basis of the variable Scan frequency), we did double coding to assess interrater reliability on 784 of the total 9,574 individual ball possessions (8.2%). The resulting overall ICC was 0.979 ($p < 0.001$), which is considered "excellent" agreement (Cicchetti, 1994). For the other variables, 166 (1.7%) of these possessions were analyzed double. For Opponent pressure, which also is a continuous variable, the ICC coefficient was 0.981 ($p < 0.001$) (indicating "excellent" agreement). For the remaining variables that were all categorical, we estimated κ values, and all agreements were considered "almost perfect": pass type $k = 0.867$ ($p < 0.001$), action type $k = 0.851$ ($p < 0.001$), action direction $k = 0.916$ ($p < 0.001$), and successful action $k = 0.978$ ($p < 0.001$) (Cohen, 1960; Landis and Koch, 1977).

Descriptive Analyses

The initial part of the statistical analyses was performed using SPSS (version 24). First, to test whether the scanning variable was normally distributed a Kolmogorov-Smirnov test was performed. Because the result showed that average scanning frequency significantly deviated from normal distribution ($D = 0.07$, $p < 0.001$), non-parametric tests were used. Second, the Kruskal–Wallis test in combination with the Dunn multiple comparison *post hoc* test were used to analyze differences in scanning behaviors under different contextual conditions (e.g., positional role, opponent pressure, pitch location, and game states). Bonferroni adjustments were conducted to control for the multiple testing procedure. Third, the Mann-Whitney U test was used to analyze differences in scan frequency between successful and unsuccessful actions. Fourth, for all analyses, Cohen d effect sizes were calculated to indicate the magnitude of the effects for each of the pair-wise comparisons, where we will discuss values that are above 0.20 (considered a small effect), above 0.50 (medium effect), and above 0.80 (large effect) (based on Cohen, 1988).

Modeling Pass Completion Using Scanning as a Predictor Variable

Hierarchical Bayesian Model With a Single Explanatory Variable

Motivation

We want to model the outcome of a pass using scanning as a predictor variable, to quantify whether it has a credible non-zero effect. To motivate our model selection, we first note that our observations of passes are *not* independent of one another, because different players pass the ball multiple times.

Player identity may play a role in pass completion in two ways. First, players have varying technical abilities: some are better at completing passes than others. Second, players may have different scanning tendencies, we may or may not find that when a player scans more (relative to their baseline), they may also have a higher probability of pass completion. The rate of improvement may be the same or varying across all players. Any pass completion model using scanning as a variable ought to account for individualized player effects.

As such, we chose to fit a hierarchical Bayesian model [see Model Description (both sections under Hierarchical Bayesian Model With a Single Explanatory Variable and Hierarchical Bayesian Model With Multiple Explanatory Variables], using the "pymc3" Python package (Salvatier et al., 2016), to estimate individualized player scanning coefficients. These are modeled as parameters sampled from an overall ("group") scanning distribution.

This approach has the added benefit of accounting for varying observational sample sizes between players. When estimating individualized player scanning coefficients, we split observations by player. However, some players have fewer scanning observations. A hierarchical Bayesian approach accounts for this through *shrinkage*: when there are fewer observations, the individualized player distribution tends to the overall group distribution.

Additionally, the Bayesian interval estimator is given by a "credible" interval (rather than a "confidence" interval), directly understood as a probabilistic measure of uncertainty around the true value of the coefficient.

Model description

The pass outcome, y_i, of the ith pass, is observed as complete ($y = 1$) or incomplete ($y = 0$), and v_i is the search frequency before the ith pass. We assume each pass is a Bernoulli trial, where $y_i = 1$ with probability p_i and $y_i = 0$ with probability $1 - p_i$. We modeled the outcome y_i using a hierarchical logistic regression (c.f. **Figure 1**; without the γ term) as follows:

$$\eta_{i|s} = \alpha_s + \beta_s v_{i|s} \tag{1}$$

where $\eta_{i|s}$ is the log-odds of pass completion for the ith pass by player s (the "subject"), and $v_{i|s}$ is the scanning frequency of that pass. α_s is the intercept term, varying for every player and accounting for their baseline technical ability. β_s is the scanning coefficient, varying for every player. There are 27 players in our dataset, therefore we will be estimating 27 α_s and 27 β_s terms, one pair per player. For this and the next model (see section *Hierarchical Bayesian Model With Multiple Explanatory Variables*), the independent variables were standardized by their mean and SD.

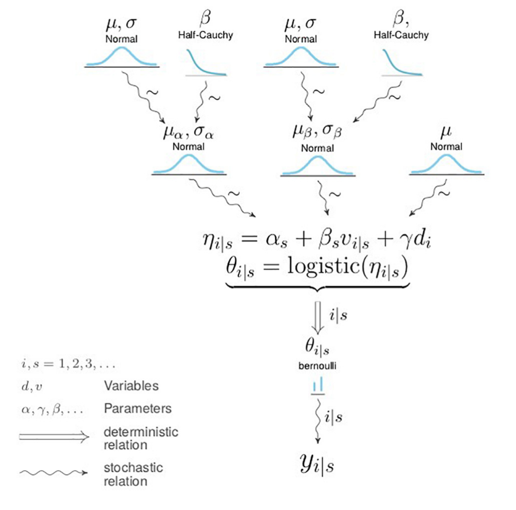

FIGURE 1 | Diagram showing the full Bayesian hierarchical model.

As we are interested in the overall group-level effect of scanning, we assume that the α_s and β_s coefficients are themselves normally distributed as follows:

$$\begin{aligned} \alpha_s &\sim \text{Normal}(\mu_\alpha,\ \sigma_\alpha) \\ \beta_s &\sim \text{Normal}(\mu_\beta,\ \sigma_\beta) \end{aligned} \tag{2}$$

where $\mu_\alpha,\ \sigma_\alpha$ and $\mu_\beta,\ \sigma_\beta$ are group-level parameters describing the overall distribution of individual technical ability and scanning tendencies respectively. We set the prior distributions on $\mu_\alpha,\ \mu_\beta$ as follows:

$$\mu_\alpha,\ \mu_\beta \sim \textit{Normal}(0,\ 1)$$

We chose these priors as we have no reason to believe that they are not continuous variables defined over the infinite range $[-\infty,\ +\infty]$; furthermore, many natural phenomena are modeled with Normal distributions, so we find it reasonable to assume that the effect of scanning (and baseline technical ability) is also normally distributed. The strength of these priors is weakly informative, but suitably so as to not unduly influence the posterior parameter distributions: given that when the log odds $\eta \approx 2.2$, $p \approx 0.9$, and when $\eta \approx -2.2$, $p \approx 0.1$, our scale parameter = 1 and does not constrain us tightly around our location parameter (= 0).

As we are unsure of the magnitude of the variance parameter, we set vague uninformative priors on $\sigma_\alpha,\ \sigma_\beta$ as follows:

$$\sigma_\alpha,\ \sigma_\beta \sim \textit{Half} - \textit{Cauchy}(\beta = 25)$$

in accordance with Gelman (2006).

For this model and the next (see section *Hierarchical Bayesian Model With Multiple Explanatory Variables*), the pymc3 NUTS sampler ("No U-Turn Sampler") was used to generate samples. Unless otherwise stated, for each model, four chains (with 2,000 tuning and 10,000 sampling steps per chain) were checked for convergence, and for each parameter the effective sample size (ESS) > 10,000 with Gelman-Rubin $\hat{R} \approx 1.000$. We use the 95% high-density interval (HDI) as the credible interval estimator: this provides the boundaries of the smallest interval within the probability distribution that contains 95% of the probability density. For model comparison, we additionally provide the Watanabe–Akaike information criterion (WAIC) score, which measures the out-of-sample prediction accuracy.

Hierarchical Bayesian Model With Multiple Explanatory Variables

Pass difficulty variable

The context of each pass (e.g., pass length, location) varies across observations. We control for these contextual factors by adding a model variable capturing the difficulty of each pass.

We define *pass difficulty*, $d \in [0, 1]$, as the conditional probability, Pr (*Pass* |*Context*), of completing a pass given various contextual factors (**Table 1**). d near 0 indicates a harder pass; and near 1 indicates an easier pass. To create d, we used a random forest (RF) model to fit 12 features to the target variable y_i, the pass outcome.

We used a single variable to encapsulate passing context for two key reasons:

1. **Model simplicity:** our focus is to have an appropriate measure of pass difficulty (i.e., develop a model that learns the conditional probability distribution Pr (*Pass* |*Context*)), not to analyze precisely why a pass is difficult;
2. **Computational efficiency:** with a single variable, we have fewer parameter estimates to make for our scanning model, which is important when running the Bayesian hierarchical model, which is computationally intensive.

We chose an RF model for multiple reasons. First, we want to amalgamate contextual factors to create the control variable, d, without needing to prescribe relationships between factors—RF models easily provide complexity (linear and non-linear). Second, RF models are quick to cross-validate and tune (i.e., grid-search optimization). Finally, and most importantly, we can calibrate and extract probability outputs from RF models. We needed to create appropriate input features (**Table 1**) in order to correctly fit to the conditional probability, Pr (*Pass* |*Context*), which we describe below.

Pass location and body orientation. Positional and body orientation data were hand-tagged by professional coders from StatDNA, LLC (c.f. section *Context*). Pass location (**Table 1**) is the player's x, y position when passing the ball (x-direction positive from the defensive-third to the attacking-third; y-direction positive from the left-wing to the right-wing). Pitch locations of both the passer and receiver were coded and transformed to a normalized range.

TABLE 1 | Pass difficulty features.

Feature	Possible values
Pass location (x, y)	$-60.0 \leq x \leq 60.0$ $-45.0 \leq y \leq 45.0$
Transformed x-position, x'	$0 \leq x \leq 60.0$
Pass distance, d	$d > 0$
Pass angle, θ	$-\pi < \theta \leq \pi$
Transformed pass angle, θ'	$0 \leq \theta' \leq 1$
Pass type	Ground, aerial
One-touch pass	True, false
Body orientation of passer	Front, sideways, backward
Opposition defensive line in front of passer	Attacking, midfield, defensive
Number of passes, n, in the possession chain until the given pass	$n \geq 0$

Body orientation of the passer at the time of their pass was coded as follows: forward (if body orientation $< \pm 45°$), sideways ($45° \leq$ body orientation $\leq 135°$ or $-45° \geq$ body orientation $\geq -135°$), or backward (| body orientation| $> \pm 135°$); where 0° is the positive x-direction. This orientation was separate to that previously used (see section *Performance With the Ball*), and here used only within the context of the hierarchical Bayesian model (see *Modeling Pass Completion*).

Pass distance, angle, transformed angle, and transformed x-position. We calculated the pass distance (c.f. see section *Context*) and pass angle using the pitch locations of the passer and receiver. We also derived two additional features. First, we transformed the pass angle to θ', where

$$\theta' = \sin\left(\frac{\theta}{2}\right).$$

Here, θ' as a measure of left-right pass asymmetry ($\theta' = 0$ when a pass is perfectly from left to right; $\theta' = 1$ when a pass is perfectly from right to left).

Second, we transformed the x-direction to x', where

$$x' = 60.0 - |x|$$

Here, x' measures the absolute x distance to an end-line of the pitch (offensive or defensive).

Pass detail. We included features relating to the pass (**Table 1**): the pass type; a flag indicating whether the pass was a one-touch pass; defensive line faced by passer; and the number of passes by the team in possession until the given pass.

Model description

We add the pass difficulty variable (see section *Pass Difficulty Variable*), d_i, into our existing Bayesian hierarchical model (c.f. section *Hierarchical Bayesian Model With a Single Explanatory Variable*) with associated parameter γ, as follows:

$$\eta_{i|s} = \alpha_s + \beta_s v_{i|s} + \gamma d_i \quad (3)$$

Unlike α_s, β_s, we do not condition γ on player s, because we assume that pass difficulty (a proxy for passing context) is the same for any passer. That is, a difficult pass is difficult for any player, but better players (with higher α_s) will have a better chance of completing that pass. We assume γ has a Normal prior distribution for the same reasons as for μ_α and μ_β (c.f. section *Model Description*).

RESULTS

General

The players performed on average 3.0 scans (±2.1) in the last 10 s before receiving the ball, giving a mean scan frequency of 0.44 scans/s (±0.30) (note that when the team won the ball or there was a set play within those 10 s, the time interval was shorter than 10 s).

Contextual Factors' Influence on Scanning

Positional Role and Scan Frequency

Scan frequency varies significantly with different positional roles on the team, with central midfielders showing the highest mean frequency and forwards the lowest mean frequency (Kruskal–Wallis $H = 669.97$, $p < 0.001$, see **Figure 2**). The effect size is $d = 0.55$, which is considered a medium effect (Cohen, 1988). *Post hoc*, pairwise comparison Dunn tests show the scan frequencies for all positional roles were significantly different from each other (all Bonferroni adjusted *p*-values <0.002) with effect sizes ranging from trivial ($d = 0.16$, central defenders and wingers) to medium ($d = 0.56$, central midfielders and side defenders).

Opponent Pressure and Scan Frequency

The scan frequency appears relatively low in situations where the opponent pressure is high (closest opponent being 0–1 m away when receiving the ball), and then progressively higher when pressure is lower (closest opponent is further away), until the closest opponent is about 4 m away where a further increase in distance is not associated with an increase in scan frequency (see **Figure 3**). A Kruskal–Wallis test shows that the difference for pressure is significant ($H = 319.90$, $p < 0.001$). The effect size $d = 0.37$ is small. *Post hoc* pairwise comparison Dunn tests show that the scan frequency for the two highest degrees of pressure (0–1 and 2 m) are different from each of the other degrees of pressure ($p < 0.002$), the third highest pressure (3 m) is different from each of the other degrees of pressure ($p < 0.003$) except 7–9 m, and the four lower degrees of pressure (4, 5–6, 7–9, and 10+ m) are only different from each of the three highest degrees of pressure (0–1, 2, and 3 m) ($p < 0.003$) (all *p*-values Bonferroni adjusted for multiple tests). The effect sizes range from trivial ($d = 0.04$ for 5–6 m compared to 7–8 m) to medium ($d = 0.57$, for 0–1 m compared to 10+ m).

Pitch Location and Scan Frequency

For passing events, on average, players scan above the 75th percentile (0.6 scans/s) when passing around their own 18-yard box, in the central area between their penalty spot and the top of the "D" (**Figure 4**). Scanning tends to be above average (>0.45 scans/s) but below the 75th percentile consistently through the left channel (we define the channel to be the width between 6-yard box and 18-yard box, here traversing the pitch from defense to attack). The right channel does not show an exact symmetry of the left channel with scanning dropping off in both the defensive third and attacking third.

Scanning decreases below average near the boundary areas (<0.3 scans/s), especially in the attacking third. It drops almost toward 0 scans/s near the defensive and attacking 6-yard box and near the right defensive corner flag. There is also a pronounced drop-off in scanning from the midfield third to the attacking third.

Game State and Scan Frequency

Game state, for the purpose of this study, was represented by game standing and accumulated game time. Game standing (whether the team at that moment is winning, losing, or drawing) was significantly, but marginally linked to scan frequency (Kruskal–Wallis $H = 7.50$, $p = 0.024$). *Post hoc* pairwise comparison Dunn tests show that scan frequency was higher

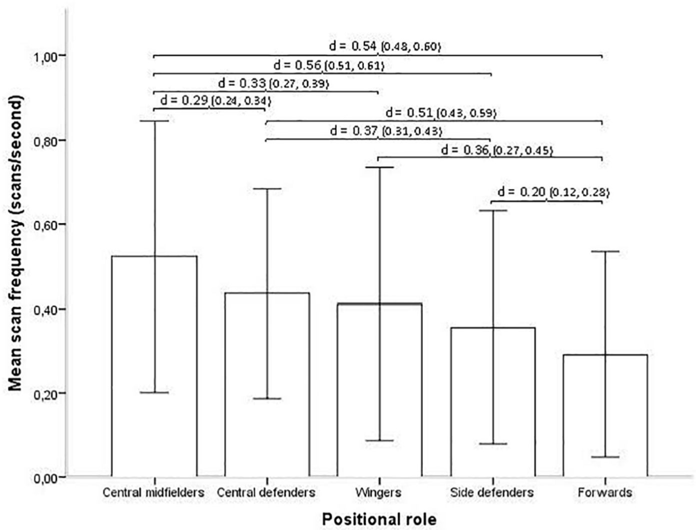

FIGURE 2 | Positional role and mean scan frequency (with SD error bars). Brackets indicate all significant relationships with an effect size >0.20, with effect size *d* and 95% confidence interval (CI) in parentheses.

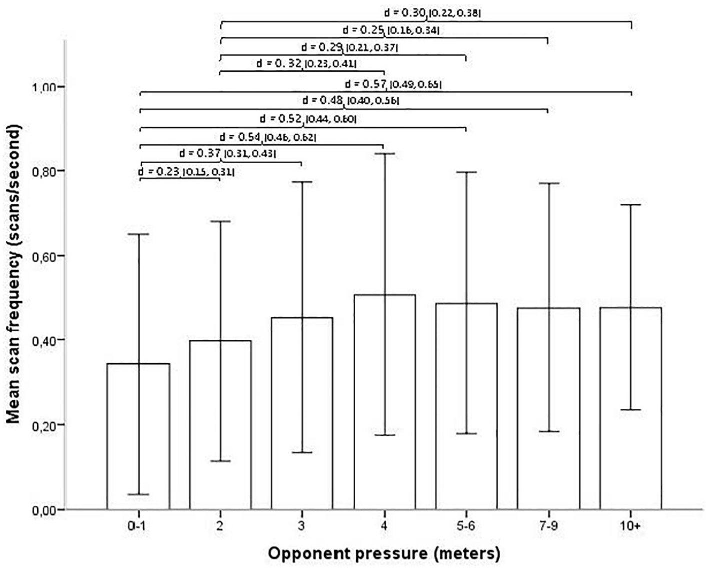

FIGURE 3 | Opponent pressure and mean scan frequency (with SD error bars). Brackets indicate all significant relationships with an effect size >0.20, with effect size *d* and the 95% confidence interval (CI) in parentheses.

when the team is losing (M = 0.46 scans/s ± 0.29, N = 912) than when the team is drawing (M = 0.44 scans/s ± 0.30, N = 4,102) (adjusted p = 0.020), but the effect size d = 0.08 suggests that this is a trivial effect. There were no significant differences with when the team is winning (M = 0.45 scans/s ± 0.31, N = 4,296) (both adjusted p-values >0.013) (effect sizes d < 0.06).

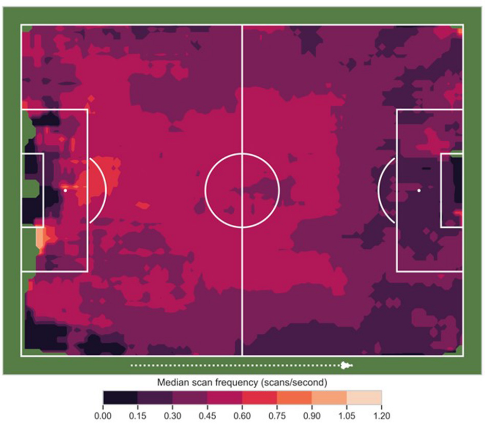

FIGURE 4 | Pitch location and scan frequency. The attacking direction is normalized from left to right (dotted arrow). Colors at a given location (*x,y,*) show the median search frequency calculated from a 12 × 8-m box centered on that point.

For game time, scanning frequency was relatively stable throughout the different time phases in the first half of the games (H = 8.99, p = 0.439), but less stable in the second half with a significant difference between the time phases (H = 24.06, p = 0.004) (N = 8,733 possessions, where only the players who started the game were included in the analysis, see **Figure 5**). However, the effect size, d = 0.12, is trivial. *Post hoc* pairwise comparison Dunn tests, where we use Bonferroni adjustments to control for the large number of tests, showed no significant differences. However, there was a trend for a difference between 76 and 80 min and 81–85 min (adjusted p = 0.062, effect size d = 0.21), and between 76 and 80 min and 90+ min (adjusted p = 0.063, effect size d = 0.23).

When we combined game standing and game time, we observed a similar pattern when the team is winning, with no differences for the first half (H = 13.29, p = 0.15, N = 1,511 possessions), but a difference for the second half (H = 23.85, p = 0.005, N = 2,645 possessions, where the *post hoc* pairwise comparisons show no significant differences). The effect size was trivial, d = 0.15. For possessions where the team is drawing, there were no differences in the first half (H = 11.30, p = 0.256, N = 2,669 possessions) or in the second half (H = 13.18, p = 0.155, N = 996 possessions). However, for possessions when the team is losing, there was no difference for the second half (H = 4.98, p = 0.836, N = 460 possessions), but there was a difference for the first half where the scan frequencies tended to drop toward the end of the half (H = 25.69, p = 0.001, N = 452 possessions,

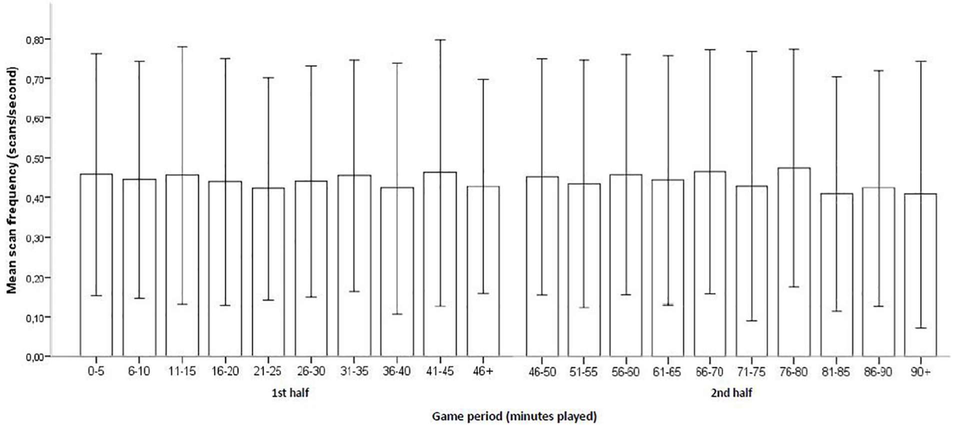

FIGURE 5 | Accumulated game time and mean scan frequency (with SD error bars).

effect size $d = 0.47$). The *post hoc* pairwise comparisons for the first half showed significant differences between 45+ min and 5–10 min (adjusted $p = 0.005$, effect size $d = 1.25$), and between 45+ min and 31–35 min (adjusted $p = 0.048$, effect size $d = 0.84$). Both these effect sizes are considered large (Cohen, 1988), but the sample sizes are very small (e.g., only 35 possessions for the 45+-min condition) and the result needs to be interpreted with much caution.

Scan Frequency and Performance

Scan Frequency and Action Direction

Analysis of the players' scanning frequency prior to their last action in a ball possession showed that players scanned more frequently prior to actions directed forward ($M = 0.46$ scans/s $\pm$ 0.31, $N = 5{,}776$), compared to sideward (0.43 scans/s $\pm$ 0.31, $N = 663$) and backward (0.42 scans/s $\pm$ 0.30, $N = 2{,}860$) (Kruskal–Wallis $H = 30.602$, $p < 0.001$, effect size $d = 0.11$). Pairwise comparison with Bonferroni corrected adjusted significance values showed a difference only between passes directed forward and backward ($p < 0.001$). The effects sizes were between $d = 0.06$ and $d = 0.12$, which suggests these were trivial effects.

Scan Frequency and Action Type

Players had the highest scanning frequency when their last action was a pass ($M = 0.45$ scans/s $\pm$ 0.30, $N = 8{,}760$), compared to a dribble ($M = 0.39$ scans/s $\pm$ 0.30, $N = 289$), receiving the ball ($M = 0.35$ scans/s $\pm$ 0.31, $N = 160$), and finishing ($M = 0.27$ scans/s $\pm$ 0.24, $N = 207$) (Kruskal–Wallis $H = 114.98$, $p < 0.001$, effect size $d = 0.22$). Pairwise comparison with Bonferroni corrected adjusted p-values show significant differences between passing and finishing ($p < 0.001$, effect size $d = 0.19$), passing and receiving ($p < 0.001$, effect size $d = 0.10$), passing and dribbling ($p < 0.001$, effect size $d = 0.08$), and between dribbling and finishing ($p < 0.001$, effect size $d = 0.42$).

Breaking down the last actions in a possession into different passing types, players scanned most frequently prior to long penetrative passes and less with passes that were shorter and/or less directed forward (see **Figure 6**) (Kruskal–Wallis $H = 64.751$, $p < 0.001$). Pairwise comparison with Bonferroni corrected adjusted significance values show significant differences between long penetrative passes and backward passes ($p < 0.001$, effect size $d = 0.24$), long penetrative passes and sideward passes ($p < 0.001$, effect size $d = 0.23$), long penetrative passes and short penetrative passes ($p < 0.001$, effect size $d = 0.19$), as well as between "forward, not penetrative passes" and backward passes ($p < 0.001$, effect size $d = 0.15$). In addition, the pairwise comparisons show significant differences between possessions where no pass is given and all the other instances of passes (all adjusted $p < 0.001$), with the effect sizes d ranging between 0.27 and 0.63.

Scan Frequency and Successful Actions

Players scanned significantly higher when possession was maintained after their actions with the ball ($M = 0.46$ scans/s $\pm$ 0.30) than when possession was lost after their action ($M = 0.37 \pm 0.30$) (Mann-Whitney $U = 4{,}540{,}860$, $p < 0.001$, $N = 9{,}510$ possessions, effect size $d = 0.20$). For those possessions where the players end up playing a pass ($N = 8{,}825$ possessions), they also scanned higher when their passes reached a teammate (i.e., pass completed, $M = 0.46$ scans/s $\pm$ 0.30) than when their passes did not reach a teammate (i.e., pass not completed, $M = 0.40$ scans/s $\pm$ 0.30) (Mann-Whitney $U = 3{,}649{,}383$, $p < 0.001$, effect size $d = 0.15$).

Modeling Pass Completion

Hierarchical Bayesian Model With a Single Explanatory Variable

Our hierarchical model generates 27 α_s and 27 β_s pairs; one per player (see section *Model Description*). These specific

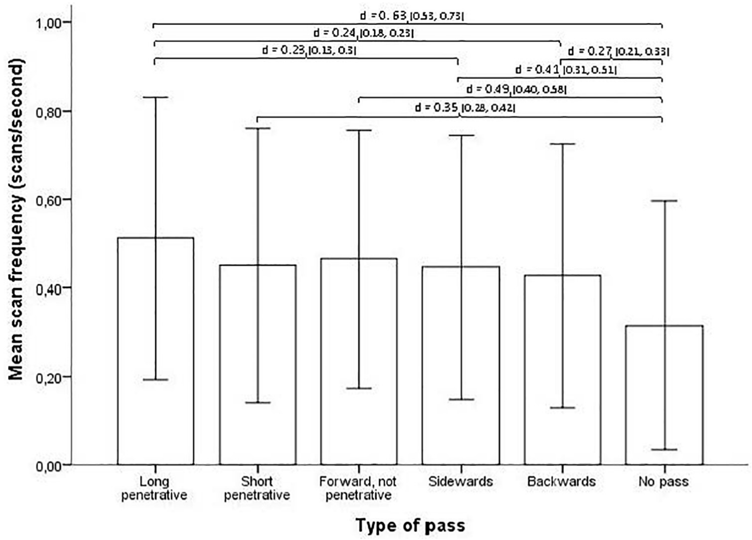

FIGURE 6 | Type of pass and Mean scan frequency (with SD error bars). Brackets indicate all significant relationships with an effect size >0.20, with effect size *d* and the 95% confidence interval (CI) in parentheses.

player parameters are assumed to be distributed from a prior normal distribution, described by μ_α, σ_α, and μ_β, σ_β, which we report here (we do not report the specific player parameter estimates, as they are not of interest compared to the estimates of the group parameters). Estimates for the group-level intercept term are: $\mu_\alpha = 2.07 \pm 0.11$ [1.86, 2.29] and $\sigma_\alpha = 0.49 \pm 0.10$ [0.30, 0.67]. Estimates for the group-level scanning coefficient are: $\mu_\beta = 0.16 \pm 0.06$ [0.03, 0.28] and $\sigma_\beta = 0.20 \pm 0.07$ [0.06, 0.34]. The σ_β ESS = 3,889.67, indicating slightly less robustness in the HDI estimate (for all other parameters the ESS $\geq$ 10, 000). The model WAIC = 5,307.21.

Hierarchical Bayesian Model With Multiple Explanatory Variables

We added pass difficulty, *d*, to the hierarchical model [see *Model Description* (under section *Hierarchical Bayesian Model With Multiple Explanatory Variables*)]. Estimates for the group-level intercept term are: $\mu_\alpha = 2.44 \pm 0.11$ [2.22, 2.67] and $\sigma_\alpha = 0.47 \pm 0.09$ [0.31, 0.67] (ESS = 1,908.7 and 4,386.2 for μ_α, σ_α respectively). Estimates for the group-level scanning coefficient are: $\mu_\beta = 0.13 \pm 0.06$ [0.02, 0.24] and $\sigma_\beta = 0.12 \pm 0.07$ [0.01, 0.24] (ESS = 3,368.1 and 1,058.6 for μ_β, σ_β respectively). Estimates for the pass difficulty coefficient $\gamma = 0.97 \pm 0.03$ [0.91, 1.03] (ESS = 5, 551.2). For all other parameters, the ESS was $\geq 3,000$ with 40% of parameters $\geq 10,0000.0$. The model WAIC = 4,122.25, which is lower compared to our hierarchical model with a single variable (WAIC = 5,307.21; see section *Hierarchical Bayesian Model With a Single Explanatory Variable*), thus indicating better pointwise out-of-sample predictive accuracy.

The log-odds of completing a pass, η, decreases as passes become more difficult ($d \to 0$; **Figure 7**). The contours have a negative slope (c.f. black dashed line): when pass difficulty is kept constant, the more a player scans, the greater the probability of completing a pass.

However the 25–75% percentile domain, within which most scan frequencies and pass difficulties lie (dark shaded area), is small relative to the practical range of η ($\eta \approx 2.2 \rightarrow p \approx 0.9$; $\eta \approx -2.2 \rightarrow p \approx 0.1$; c.f. section *Motivation*). The magnitude of the group intercept term, μ_α, dominates the latent variable equation (Eq. 3) and its variability is on the same scale as the group scanning coefficient, μ_β. Pass difficulty, *d*, plays the second largest role in pass completion. This indicates that the advantage of increased scanning is much smaller than players' intrinsic technical abilities and the passing context.

DISCUSSION

The study was conducted to learn more about how 27 EPL professional football players use scanning prior to their individual ball possessions during 21 competitive games, across a season. We hypothesized that scanning frequencies increase in certain positions and situations, specifically when playing centrally in the field and under loose pressure from opponents, and that scanning is related to performance with the ball. Overall, the results supported these hypotheses, and showed that these players' scanning varied with different types of contextual demands (i.e., positional role, opponent pressure, pitch location, and to some extent game state), although some of the differences were small

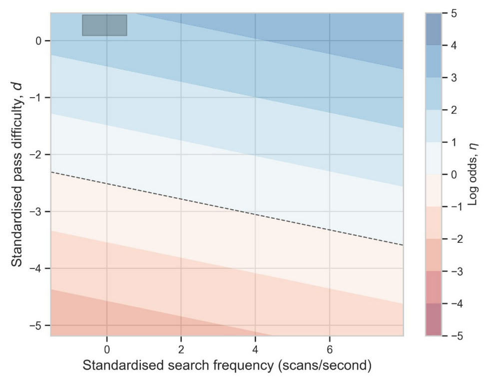

FIGURE 7 | Contour plot of the log-odds, η, plotted for different standardized values of the search frequency, *v*, and pass difficulty, *d*, using the coefficients μ_α, μ_β and γ (Eq. 3). The 25th and 75th percentile values for *v* and *d* are shown (dark gray shaded box). Probability of pass completion is ≥ 50% above and < 50% below the black dashed line.

(i.e., effect sizes between 0.2 and 0.5). Moreover, scanning prior to receiving the ball was linked to performance with the ball, in that players in situations where they scanned more produced more passes, more long penetrative passes and more successful actions with the ball, but these effects were also quite small. Our more statistically sophisticated pass completion models show that scan frequency played a small, positive role for players completing their passes. Here, we will discuss these findings more in detail.

Contextual Influences

Players that hold different positional roles showed different degrees of scanning frequency. Defenders and midfielders with central positions (central midfielders and central defenders) displayed higher scanning frequency than players along the sides of the field (particularly side defenders, but also wingers, even though this difference was smaller) or players relatively higher up in the field (forwards). This is consistent with the finding from a previous study that central players scanned more than wide players when they, or their team, had possession of the ball (McGuckian et al., 2020), and with another study showing that central midfielders and central defenders are the most prominent playing positions when building an attack in football (Clemente et al., 2015).

Although we here will conjecture that players in certain positions scan less than others because of logical requirements from the game, it is possible that they scan less in certain situations even though they should scan more. With that said, an explanation for this finding could be that centrally (as compared to more peripherally) located players are constantly surrounded by both teammates and opponents, which logically necessitates more frequent scanning to obtain and update the informational basis for one's actions. Previous research has shown that players' space exploration ability is influenced by space restrictions (Gonçalves et al., 2017). Hence, the inherent space constraints for peripherally positioned players are likely also to influence their scanning ability. Moreover, players located along the edges of the field can logically restrict the orientation of their scanning to one direction, inward in the field (i.e., they do not have to scan for information in the direction of the sideline, as there is no relevant information outside the field).

Forwards scan with a lower frequency than the other positional roles, and we hypothesize a few possible explanations for this. First, forwards are likely to receive the ball in tighter areas that are more guarded by opponents. If ball receiving precision drops here, and it would seem likely to do so if the forward takes his eyes off the ball at an inopportune time, the ball is likely to be lost. Second, forwards may scan less in the seconds before they receive the ball because they typically are so close to defenders that they perceive where they are without having to scan (e.g., from physical contact or from peripheral vision) and/or because a prearranged game plan/game model stipulates some of the likely surroundings making scanning less necessary. Third, forwards contribute less than any other position in the attacking build up (Clemente et al., 2015). Consequently, when forwards are about to receive the ball, their visual attention is likely more narrowly directed toward finishing an attack (with less scanning for surrounding passing options) compared to central midfielders who will scan for teammates in order to build up an attack (Clemente et al., 2015).

The results for location in the field and scanning are to a large extent aligned with the results for positional role and scanning. As indicated in **Figure 4**, scanning frequency is relatively low in both far ends of the field. There is a distinct drop from the midfield third to the attacking third, and there are somewhat lower scan frequencies along the sidelines as compared to a central channel between the two goals. Scanning is relatively high in several sections of the players' own half, possibly because players on the team in possession of the ball have to be very aware of their opponents, given that losing the ball here might have disastrous consequences. At the same time, they typically have the game in front of them, more space around them and time to scan and fully prepare the reception of a potential pass. Interestingly, only parts of these results are in line with a recent study where elite youth players indeed scanned more frequently in central as opposed to wide areas of the field, but less frequently in the middle third than in the back and front third of the field (McGuckian et al., 2020). It is possible that the difference in performance level (professional Premier League players vs elite youth players) may account for this difference.

The results for opponent pressure and visual scanning support the results for positional role and field location, although with the biggest difference between situations under tight pressure (receiving the ball with closest opponent being 0–1 m away) and situations under considerably looser pressure (i.e., 4 m or more away) (medium effect sizes). That the players in this study scan less frequently when the closest opponents are less than 1 m away could be due to the heightened risk of taking their eyes off the ball when opponents are near. Also, when defenders are that close, the players receiving the ball may already be aware of the defensive threat (due to physical body contact or peripheral awareness of the defender), thus reducing the need to scan.

The players in our study seem to scan significantly, but marginally less frequently toward the end of the second half of a game, as compared to earlier in the second half. This would be consistent with studies showing that football players' running seems to drop toward the end of the game (Carling et al., 2015). The same drop in scanning frequency was evident under conditions where one's team was in a lead. When the team was behind in the score, there was no drop in the second half, but indeed a drop toward the end of first half. Certainly, our data on this topic is far from conclusive and our interpretations are extremely tentative. This would be enhanced by structured input from coaches, and more focused research is needed to be able to say more about some of the mechanisms that may underlie these observations.

Scanning and Performance

The main objective with our study was to examine the potential role that scanning plays for different types of performance with the ball. In general, scanning frequency was associated with more passes (compared to dribbles and shots), more long and forward passes, and more dribbles (compared to shots). Even though most of these effects were small, the results might imply that engaging in scanning lead players to more effectively detect and utilize progressive/forward-passing opportunities. Such association between scanning and type of action would be consistent with those from previous studies on elite youth players (Eldridge et al., 2013) and semi-elite adult players (McGuckian et al., 2018) showing that scanning is associated with more forward passes.

Importantly, with our Bayesian hierarchical model, the data we have collected adds evidence toward the hypothesis that increased scanning increases the probability of completing passes. This conclusion is maintained when controlling for differences between players and the difficulty of passes. Lowest case estimates of μ_β suggest that for ≈ 53% of players scanning plays a positive role in pass completion ($Z = 0.08$). Highest case estimates suggest that for ≈ 100% of players scanning plays a positive role ($Z = 24.0$). Mean estimates suggest that for ≈ 86% of players scanning plays a positive role ($Z = 1.08$). Thus, the more players scan prior to receiving the ball, the more likely they are to play a successful pass to a teammate. This agrees with results from previous studies at the same level of performance (Jordet et al., 2013) and could be consistent with the finding that higher scanning frequency is associated with faster response time (McGuckian et al., 2019), which is likely a sign that increased rate of scanning produces more accurate perception which would positively affect pass completion. However, the result is counter to results from field studies with players at a lower level of performance that do not find this relationship (Eldridge et al., 2013; McGuckian et al., 2018).

Based on the theoretical premise that active perception is better than passive perception (Adolph et al., 2000), it makes sense that more extensive visual exploration of one's surroundings is linked to more accurate perception and subsequent performance toward the same surroundings. Ecological psychologists will argue that a major advantage of engaging in exploratory scanning activity is that the payoff in terms of information located and used can be quite large, yet the energetic expenses are minimal (Reed, 1996). More specifically, this is in line with Gibson's (1979) concept of affordances which states that action possibilities can be found through actively exploring the environment, and it is only when a player continually updates himself that he is able to see which opportunities are opening up and closing down (Marsh and Meagher, 2016). Interestingly, extensive research has shown that individuals are not only attuned to their own affordances but also sensitive to the action possibilities of other individuals in their environment (i.e., teammates and opponents) (Marsh and Meagher, 2016). Hence, by scanning more, players will be attuned to more opportunities for action for themselves as well as having an increased awareness of the affordances of their direct opponent and teammates, which in turn should lead to an enhanced prospective control of their actions (Fajen et al., 2008).

However, our predictive models suggest that while increased scanning conferred a small advantage on pass completion, this was small. A player's technical ability and the difficulty of a pass (embedded in a team's familiar game model) are likely still primarily responsible for pass completion. Researchers are advised to continue to examine the extent to which scanning may be related to performance, and the different mechanisms that may support such a relationship. This includes pursuing research on aspects around scanning that we were not able to focus on here, such as scan excursion (which would say something about the scope of information gathered in each scan McGuckian et al., 2018, 2019) and defensive scanning (scanning when the other team has the ball).

Limitations

There are several limitations with this study that suggest the results need to be interpreted with caution.

First, even though the number of individual ball possessions analyzed is relatively high (almost 10,000), the players in the study all came from only one team, and the results are not necessarily representative for other players and teams, even at the same high level of performance. The particular team that was analyzed in this study is known to play possession-based football, and it is possible that an analysis of players on teams that follow a different game model would give different results.

Second, all the games were played at home, and given that we know the home advantage has a robust impact on results in professional football games (including those in the EPL, Pollard and Gómez, 2014), it is possible that these players would have behaved somewhat differently when they play away.

Third, although a very strict observation protocol was followed and interreliability test scores were very good, manually coding this type of behavior in a fluid and complex field event will undoubtedly be associated with measurement errors. In our position assessments, we did not fully account for the instances where a player changed position late in the match, which should be better captured in future research. Also, future researchers need to continue to improve and refine the quality of scanning measurements, which includes learning more about the conditions where scanning is easy and difficult to accurately assess. Related to that, there is a need to explore the cutoff values for the time interval in which scanning is measured, as other intervals than 10 s could be more adaptive in certain game phases and situations.

Practical Applications

Despite methodological limitations, we can suggest some general applied implications from this study. The results provide some support that scanning is a process that practitioners could focus on to help football players improving their pickup of visual information, to facilitate performance. Previous studies have shown that even relatively short interventions have the capacity to help football players at the professional (Jordet, 2005b) and elite youth academy levels (Pocock et al., 2017) increase their rate of visual scanning and that this again might positively support performance (i.e., improvements in performance were noted for some of the players in both those studies). Indeed, coaches have started to integrate exercises on scanning into their practices (e.g., Jozak and Kepcija, 2017; Pulling et al., 2018) and emerging technological innovations are addressing this skill (e.g., the Footbonaut, Beavan et al., 2018). Our study lends some tentative support to continue work in this direction.

In general, as sport psychology practitioners we seek to support athletes' ability to place, change and control their attention. Having insights into how they go about gaining information is a fruitful pathway into performance enhancement discussions with players and coaches. Some of the practical questions to players could be, what do coaches want them to look for? What cues? When do coaches want them to look, and when not to? What are the crucial moments within a game that interest coaches and to what extent do players gain or miss crucial information in split-second moments that often define a game? Similarly, practitioners can facilitate the integration of the behaviors into exercises and game-based activities in training. Further, coaches and analysts often analyze football games, in the moment and after games, using video technology. While in the future we may have the athletes' own eye view, on ground level, at this time, analysis is often done from a bird's-eye view. Inferring from above (often in comfort on a screen), what goes on for a player is very different looking down than on the ground in the moment and might arguably lead to unrealistic and unfair interventions that do not represent the actual experience of the player. With this study, we do not wish to feed this divide but instead find innovative ways to close it.

CONCLUSION

Elite professional football players competing in an EPL team engaged in frequent visual scanning behaviors in the seconds prior to receiving the ball. There were some positional and contextual differences in scanning, which can be explained by the requirements of different phases and aspects of the game. Through a statistically sophisticated model, our data added evidence toward a positive, albeit small, relationship between scanning and pass completion, suggesting that scanning can play a positive role for pass completion. With that said, particularly given that many of the differences we uncovered were relatively small or modest, we do not believe or claim that scanning is the conclusive variable associated with football performance. Innumerable and immeasurable factors can affect a player and team performance at any given time (on or off the grass). Instead our interest with this article lies in exploring this one variable, on the grass, in the game, knowing its incompleteness, but also its future potential to be linked with other multidisciplinary data that could lead to fascinating and insightful dialogue and interventions with players and coaches if the marriage of technology and human relationships continue to strengthen.

DATA AVAILABILITY STATEMENT

The data generated for this study are available upon request to the first author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Norwegian Centre for Research Data (NSD, project number 57718). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

GJ contributed to conceptualization, administration of data collection, data analysis and writing the manuscript. KMA contributed to conceptualization, data collection, parts of the data analysis and writing the manuscript. DNP contributed to conceptualization, data collection, data management, and administration of data analysis. AW contributed to data management and writing the manuscript. AT contributed to the data analysis, modeling and writing the manuscript. AM contributed to data analysis and writing the manuscript. AI contributed to data analysis and writing the manuscript. DP contributed to conceptualization, data analysis, and writing the manuscript. All authors contributed to the article and approved the submitted version.

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Paper II

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Scanning activity in elite youth football players

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Scanning activity in elite youth football players

Abstract

The purpose of this study was to analyze the scanning behavior of elite youth football players across different playing positions and age groups during high-level matches. Data was obtained by filming the 2018 UEFA European U17 and U19 Championship semi-finals and finals. A total of 53 outfield players from the four teams that reached the finals were analyzed in both their respective semi-final and final matches, resulting in a total of 1686 attacking play situations. Ecological psychology provided us with the theoretical rationale for the study and informed our research hypotheses and interpretations. We found that U19 players performed more scans than U17 players. A positive relationship between scan frequency and pass success was also found. The results further suggest that opponent pressure and pitch position are both critical contextual factors that may influence scanning behavior. In addition, central midfielders and central defenders were found to have higher scan frequencies than players in other positions. Our results support and extend previous research, suggesting that playing positions and age groups are important factors that impact visual perception and specifically scanning in football. Potential implications for coaches and recommendations for future studies are discussed.

Keywords: football, match play, talent development, exploratory activity, match analysis, elite youth, visual perception, scan frequency

Introduction

Knowing where and when to look is vital to successful performance in many different sports (Panchuk & Vickers, 2013) and is especially correlated with experts' superior decision-making (Mann, Causer, Hiroki, & Runswick, 2019). In football, scanning refers to the frequency of information-gathering head–eye movements away from and back toward the ball.[1] Scanning has been found to impact the performance of both expert (e.g., Jordet et al., 2020) and youth players directly (Eldridge, Pulling, & Robins, 2013). Thus, the study of visual perception, and scanning in particular, has become a key research area in football, examining performance (e.g., McGuckian, Cole, Chalkley, Jordet, & Pepping, 2019), talent development (e.g., Savelsbergh, Haans, Kooijman, & van Kampen, 2010), and expertise (e.g., Savelsbergh, Van der Kamp, Williams, & Ward, 2005).

Studies on players from the English Premier League (EPL) and European Championships have demonstrated a positive relationship between the frequency of scanning and pass completion (Jordet et al., 2020; Jordet, Bloomfield, & Heijmerikx, 2013; Phatak & Gruber, 2019). Moreover, these studies have shown that closer opponent pressure negatively influence scan frequency (Jordet et al., 2020), that higher scan frequencies may lead to fewer turnovers (Phatak & Gruber, 2019), that players who received individual awards had higher scan frequencies than other players (Jordet et al., 2013), and that players in different playing positions differ in scan frequencies

[1] There is a degree of uncertainty around the terminology used to describe the concept of scanning. Previous research has used similar concepts, such as visual exploratory behavior, exploratory search, checking your shoulder, head excursion, and head turns. Based on our review of the research literature (Gibson, 1979; Jordet et al., 2020; Reed, 1996), we have used the term scanning in this study.

(Jordet et al., 2020). Central midfielders exhibited the highest scan frequencies, followed by central defenders, wingers, wide defenders, and finally strikers. Moreover, the highest scan frequencies have been found in the defensive and middle third of the pitch, as well as in the central areas (Jordet et al., 2020).

Other studies of similar conceptualizations have shown that head turns[2] and head excursions impact football players' performance with the ball and are influenced by the players' pitch and playing positions (McGuckian, Cole, Chalkley, Jordet, & Pepping, 2020), the timing of the head turns (McGuckian, Cole, Jordet, Chalkley, & Pepping, 2018) and the players' age (McGuckian, Beavan, Mayer, Chalkley, & Pepping, 2020). For instance, researchers found that U23 players had higher head turn frequencies in the exploration phase (before receiving the ball) compared to U13 players when attempting to receive and pass the ball in a Footbonaut (McGuckian, Beavan, et al., 2020)

In a recent review, McGuckian, Cole, and Pepping (2018) found that the research into visual perception in football, to date, has had many conflicting findings related to representativeness and level of expertise, making it difficult to draw conclusions. Not surprisingly, empirical research has found differences in the perceptual-cognitive relationships underpinning expert performance in laboratory studies and real-world settings (Mann, Williams, Ward, & Janelle, 2007; van der Kamp, Rivas, Doorn, & Savelsbergh, 2008). Consequently, there is a need for more research to ensure ecological validity by studying representative tasks (Broadbent, Causer,

[2] This concept is similar to an exploratory scan but is not the same. A scan, as measured in this study, would include at least two head turns. This distinction should be highlighted, as it affects both the research design and the interpretation of the findings.

Williams, & Ford, 2014) in context-specific performance-environments (e.g., Eldridge et al., 2013) without any restrictions (Hüttermann, Noël, & Memmert, 2018).

It has been proposed that ecological psychology, and especially the theory of direct perception (Gibson, 1979), can provide a comprehensive framework for understanding the relationship between visual perception and action in sports (McGuckian et al., 2019). The theory of direct perception states that all the information needed to act is dynamically evolving and continuously available in the performance environment, without the need for the performer to involve processes of memory (Gibson, 1979). To explain how direct perception works, Gibson proposed the concept of affordances (Gibson, 1979). Affordances are opportunities for action that shape an individual's behavior and are embodied in the surrounding objects, events, and places (Reed, 1996). In game situations, affordances dynamically evolve every moment as a result, for example, of gaps opening between moving players or changes in playing conditions (Fajen & Riley, 2008). Affordances are, therefore, closely linked to scanning behavior in football because players must actively explore their environment in order to discover appropriate affordances (McMorris, 2004), which subsequently regulate their prospective actions (McGuckian et al., 2019; Pepping, Heijmerikx, & De Poel, 2011).

In football, exploration (scanning) will lead to more emerging affordances for the player to act upon. For instance, an attacking midfielder who is about to receive a pass between the midfield and defensive line of the opponent scans their surroundings multiple times in order to detect and choose between the different emerging affordances: Is there space to dribble? Is there a gap to play the ball through to the winger or striker? Is the defender's pressure so tight that the only safe action is to pass the ball backward immediately? Furthermore, the affordances a player experiences are shaped and constrained by their individual action capabilities (Reed, 1996), meaning that players with different experiences, physical characteristics, technical skills, and tactical awareness perceive and direct their attention toward different affordances (Vaughan, Mallett, Davids, Potrac, & López-Felip, 2019).

The interdependent relationship between perception and action has been previously explored through empirical research on different sports and sports activities, such as football (McGuckian, Cole, Jordet, et al., 2018), cricket (Pinder, Renshaw, & Davids, 2009), combat sports (Krabben, Orth, & van der Kamp, 2019), rugby (Correia, Araujo, Cummins, & Craig, 2012), fast-ball sports (van der Kamp et al., 2008), and ball catching (Stone, Maynard, North, Panchuk, & Davids, 2015). However, research examining scanning behavior in football match play specifically is still scarce. Little is known about how different contextual demands (i.e., opponent pressure, pitch position, and playing position) and different playing levels (i.e., Under-17 (U17) v Under-19 (U19)) influence scanning behavior. To the best of our knowledge, no previous research has investigated scanning activity across all playing positions, exploring differences between elite youth players in different age cohorts in competitive match play at the highest international level.

Hence, the purpose of this study was to examine how the scanning behavior of some of the best elite youth football players in Europe related to players' performance, according to situational, context-specific, and temporal constraints. Based on our theoretical assumptions and the literature reviewed, we developed five hypotheses. First, we hypothesized that the players who played in the Union of European Football Associations (UEFA) European U19 Championship would have higher scan frequencies than U17 Championship players. Second, we hypothesized that higher scan frequencies would lead to better performances with the ball. Third, we hypothesized that higher scan frequencies before receiving the ball would lead to a more forward-oriented body position when receiving the ball, based on increased situational control. Fourth, we hypothesized that closer opponent pressure and wider pitch positions would lead to decreased scan frequencies. Fifth, we hypothesized that central defenders would scan more frequently than wide defenders (fullbacks) and that central midfielders would scan more frequently than wide midfielders (wingers).

Methods

Participants

The participants were outfield players (N = 53, M_{age} = 18.0, SD = 1.15) from the four teams who reached the finals in the 2018 UEFA European U17 (n = 24, M_{age} = 16.9, SD = 0.4) and U19 (n = 29, M_{age} = 18.9, SD = 0.4) Championships. Written information was sent to the respective national head coaches with a request that they inform their players that the team would be part of the study. Players could choose not to participate in the study by replying to the first author. No players expressed a wish to be excluded from the study. The Norwegian Centre for Research Data approved the study protocol (reference number 60888).

Data collection

Data was collected by filming the semi-finals and finals of the 2018 UEFA European U17 and U19 Championships. Permission to film the matches was granted by the UEFA. All matches were recorded on-site by the first author with a Panasonic AG-UX90 4K Camcorder. The camera was attached to an adjustable tripod and situated near the halfway line on a camera platform above the main stands in the respective stadiums. The camera's position and the filming itself were conducted to ensure that the ball and as many outfield players as possible were visible inside the frame at any given time. The camera manually followed the ball.

Measures and variables

Based on the work of Jordet (2005), we defined a scan as a self-initiated head movement in which the player's face is temporarily directed away from the ball, presumably to look for teammates, opponents, the referee, or space relevant to subsequent action with the ball (see Figure 1).

Figure 1. A five-part illustration of a football player looking at the ball and then performing a scan to his left side.

Scan frequencies were assessed by dividing the total number of situational scans by the situational duration. Any scanning activities were registered in the 10 seconds leading up to the receipt of a pass (Jordet et al., 2013). The scan had to be initiated before ball contact to be included in the analysis. We exclusively measured the number of scans in the attack, meaning that if a turnover occurred within the 10-second period, our analysis began the moment the attacking team achieved control of the ball by touching it. The analysis stopped the moment the analyzed player first touched the ball. Furthermore, only situations in which the analyzed player received a pass from a teammate were included in the analysis. Other operational definitions are included in Table 1.

Table 1. Variables and operational definitions.

Variable	Sub-categories	Definition
Time from scan to ball contact		The period between when the different scans were initiated and when initial contact was made with the ball.
Ball touches		The total number of touches on the ball that the analyzed player used in a specific situation.
Body orientation	Backward, sideways, forward	The direction of the frontal (anterior) side of the analyzed player's body (chest and hip) in relation to the team's attacking direction at the moment the player made initial contact with the ball. For instance, if the player received the ball with his chest and hip facing his own goal line, the orientation was categorized as backward.
Opponent pressure	0–3 m (tight pressure, n = 529); 4–6 m (medium pressure, n = 435); 7–9 m (loose pressure, n = 262); 10–32 m (no pressure, n = 460)	The distance in meters between the analyzed player and the closest opponent at the moment when initial ball contact was made (Jordet et al., 2020). If the player had bodily contact with an opponent, it was registered as 0 meters. The stated grouping was categorized to ensure a preferably uniform distribution. Furthermore, the grouping and description of the different ranges of pressure (tight, medium, loose, and no) were assessed and approved separately by two UEFA A-licensed coaches with more than 70 years of combined coaching experience.
Playing position	Central defender, fullback, central midfielder, winger, striker	The position the player played in for most of the analyzed game.
Pitch position		The player's position on the pitch when receiving the ball from a pass. The pitch was divided into four horizontal zones of identical length and four vertical zones, where the two outer zones were outside the 18-yard box on both sides (similar to McGuckian, Cole, et al., 2020) (see Figure 4).
Pass result		*Successful pass:* A pass that reached its intended teammate without the interference of an opponent player. *Unsuccessful pass:* A pass that did not reach the intended teammate.
Pass type	Long breakthrough, short breakthrough, forward without breakthrough, across the pitch, supportive	The different types of passes registered (Jordet et al., 2020). *Long breakthrough:* A forward pass where the intention was to play the ball past two or more players and past two or more lines of defense. *Short breakthrough:* A forward pass where the intention was to play the ball past one or more players but only past one line of defense. *Forward without breakthrough:* A forward pass where the intention was to play the ball forward

		without breaking through a line of defense. *Across the pitch:* A neutral pass where the intention was to play the ball across the width of the pitch. *Supportive:* A backward pass where the intention was to play the ball from a position closer to the opponents' goal line toward a position closer to the player's team's own goal line.

Data analysis

Of the 2039 individual ball possessions analyzed in this study, only situations in which the analyzed player made an attempted pass as his last action were included, totaling 1686 situations. This selection was based on the assumption that the number and timing of scans impacted the follow-up action with the ball. Additionally, this selection allowed for comparisons of results across all situations. The result of the pass, the number of ball touches, and body orientation were used as dependent variables. To obtain a more contextual understanding of scanning activity, we also analyzed variables of opponent pressure, playing position, and pitch position. Additionally, the time from scan to ball contact was included in the study to provide insight into when the scans were conducted.

Statistical analysis

A UEFA B-licensed football coach and an undergraduate student with extensive analysis training and experience conducted a re-analysis on 10% of the complete data set ($n = 204$). Cohen's kappa was used to determine interrater reliability. The test showed perfect correlation for the number of touches ($k = 1$, $p < 0.005$) and nearly perfect agreement for total scanning behaviors in a situation ($k = 0.889$, $p < 0.005$), body positions ($k = 0.985$, $p < 0.005$), opponent pressures ($k = 0.995$, $p < 0.005$), pitch positions ($k = 0.995$, $p < 0.005$), and pass results ($k = 0.920$, $p < 0.005$).

To explore the relationship between scanning behavior and the result of a pass, a mixed-effects logistic regression was performed. Further, linear mixed models were fitted with the (separately considered) fixed effects of the number of ball touches and body orientation. To investigate the effects of contextual variables and timing, linear mixed models were fitted. Tukey post-hoc tests were computed to compare different groups, especially for body orientation, opponent pressure, and playing position.

All statistical tests were conducted using SPSS (Version 25) and the R statistical software (R Development Core Team, 2014). Linear mixed model fitting was performed using the lme4 package (Bates, Mächler, Bolker, & Walker, 2014). Mixed-effects logistic regression was performed using the car package (Fox & Weisberg, 2019). Estimated marginal means were calculated using the Emmeans package (Lenth, 2019) and effect sizes for linear mixed models were calculated according to Westfall, Kenny and Judd (2014).

Results

The players performed 0.42 ± 0.3 scans per second (s/s) on average, (n_{player} = 53, n_{pass} = 1686). Comparing U19 (n_{player} = 29, n_{pass} = 1089) and U17 players (n_{player} = 24, n_{pass} = 597), we found that U19 players performed significantly higher scan frequencies (*M* = 0.45 s/s, *SD* = 0.3) than U17 players (*M* = 0.36 s/s, *SD* = 0.3), $\chi^2(1) = 5.31$, $p < 0.05$, d = 0.31, thus supporting our first hypothesis that U19 players would have higher scan frequencies than U17 players.

Pass result

In line with our second hypothesis that higher scan frequencies would lead to better performances with the ball, the results show a positive relationship between scan frequency and pass completion rate (n_{player} = 53, n_{pass} = 1686). Players who played a successful pass performed an average of 0.43 s/s (*SD* = 0.29) before receiving the ball. When players played an unsuccessful pass, the scan rate was 0.36 s/s (*SD* = 0.3). To ascertain this effect, mixed-effects logistic regression was performed. The logistic regression model was statistically significant, $\chi^2(1) = 8.0$, $p < 0.01$.

For forward passes (subdivided into forward passes without breakthroughs, short breakthroughs, and long breakthroughs), we found a significant interaction between scan frequency and successful passes (n_{player} = 51, $n_{forwardpass}$ = 1000), $\chi^2(2) = 13.60$, $p < 0.01$. More specifically, players performed higher scan frequencies before they received the ball when they made a successful short breakthrough pass (0.46 s/s, *SD* = 0.32) compared to when they made an unsuccessful short breakthrough pass (0.30 s/s *SD* = 0.27), $z = -0.13$, $SE = 0.03$, $p < 0.001$, $d = 0.22$. No statistical differences on pass completion was found in the other forward pass types.

Ball touches

When receiving the ball from a pass, the players touched the ball 2.5 times (*SD* = 2.65), on average. The analysis showed that when players performed more scans before receiving the ball, the number of ball touches increased. Statistical testing indicated a significant main effect, $\chi^2(1) = 5.52$, $p < 0.05$; however, this effect was not strong (β = 0.28).

Body orientation

We assessed the mean scan frequencies for different types of body orientations (see Table 2).

Table 2. Scan frequency and body orientation in relation to the team's attacking direction at the moment of receiving.

Body orientation	Scan frequency		
	M	*SD*	*N*
Forward	0.44	0.30	857
Sideways	0.43	0.32	522
Backward	0.34	0.26	307
Total	0.42	0.30	1686

Using a linear mixed model, we found that scan frequency was significantly related to body orientation, $\chi^2(1) = 30.10$, $p < 0.001$. To determine the differences between body orientations (backward, sideways, and forward), a Tukey post-hoc analysis was conducted. The test revealed significant differences between backward and forward body orientation, $z = -0.11$, $SE = 0.02$, $p < 0.001$, $d = 0.24$ and between backward and sideways body orientation, $z = -0.1$, $SE = 0.02$, $p < 0.001$, $d = 0.22$. Thus, the more often a player visually explored his environment, the more likely he was to be oriented sideways or forward rather than backward at the moment he received the ball, partly supporting our third hypothesis that higher scan frequencies would lead to a more forward-oriented body position when receiving the ball.

Body orientation in relation to the timing of the last scan was also analyzed. Here, timing refers to the period between the initiation of the last scan and when ball contact is made. The results revealed differences between body orientations related to scan timing, $\chi^2(2) = 27.0$, $p < 0.001$. Significant differences between backward and forward orientations were revealed, $z = 0.6$, $SE = 0.12$, $p < 0.001$, $d = 0.3$ as well as between forward and sideways, $z = -0.3$, $SE = 0.1$, $p < 0.01$, $d = 0.12$. When the last scan was conducted closer in time to the first ball contact, players were more likely to be oriented forward ($n_{pass} = 762$, $M = 1.49$ s, $Mdn = 1.16$ s, $SD = 1.53$) than sideways ($n_{pass} = 447$, $M = 1.83$ s, $Mdn = 1.36$ s, $SD = 1.61$) or backward ($n_{pass} = 244$, $M = 2.11$ s, $Mdn = 1.62$ s, $SD = 1.78$) (see Figure 2). A total of 1453 situations were included in this analysis. Situations without scans were excluded.

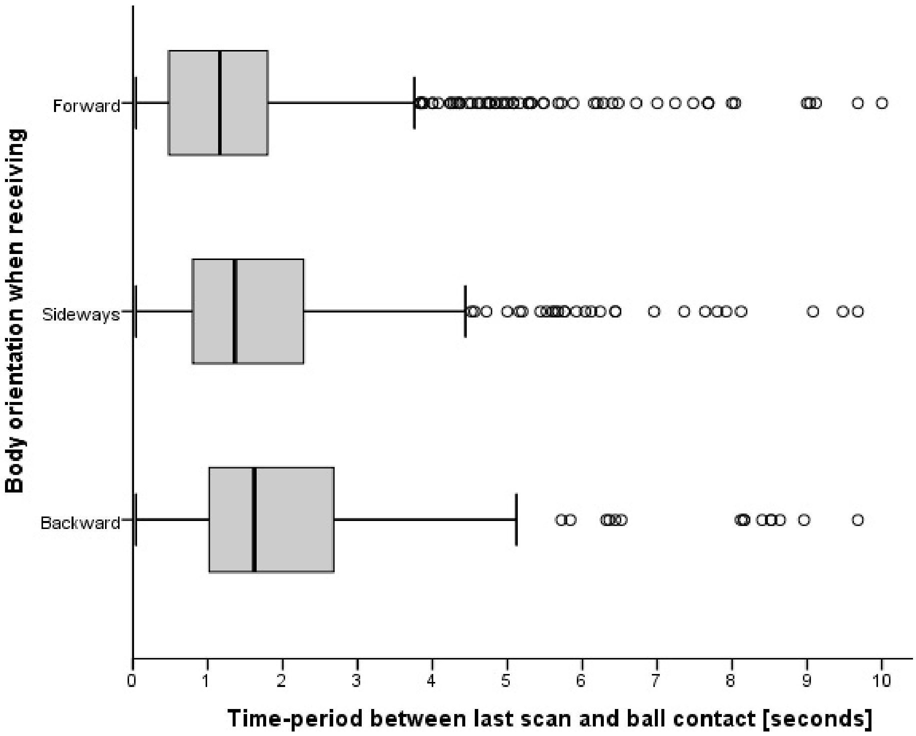

Figure 2. Boxplots of body orientation when receiving according to the time-period between last scan and ball contact. The box represents the middle 50% of scores, line inside box represents the median, the distance between the edge of the box and the lower and upper error lines represent the lowest and top 25% scores respectively, excluding outliers, and circles represent outliers.

Opponent pressure and pitch position

To analyze the relationship between opponent pressure and scan frequency before receiving the ball, opponent pressure was categorized into groups (n_{pass} = 1686): tight pressure (n_{pass} = 529, *M* = 0.32 s/s, *Mdn* = 0.30 s/s, *SD* = 0.28), medium pressure (n_{pass} = 435, *M* = 0.43 s/s, *Mdn* = 0.40 s/s, *SD* = 0.31), loose pressure (n_{pass} = 262, *M* = 0.50 s/s, *Mdn* = 0.43 s/s, *SD* = 0.36), and no pressure (n_{pass} = 460, *M* = 0.47 s/s, *Mdn* = 0.48 s/s, *SD* = 0.25). Using a linear mixed model, we identified an effect for the pressure groups, $\chi^2(3) = 67.0$, $p < 0.001$. A Tukey post-hoc analysis revealed significant differences in scan frequency between tight and loose pressure, $p < 0.001$, $d = 0.47$, between tight and no pressure, $p < 0.001$, $d = 0.37$, and between medium and loose pressure, $p < 0.01$, $d = 0.21$ (see Figure 3), supporting our fourth hypothesis that closer opponent pressure would lead to decreased scan frequencies. However, there were no significant effects for age or interactions.

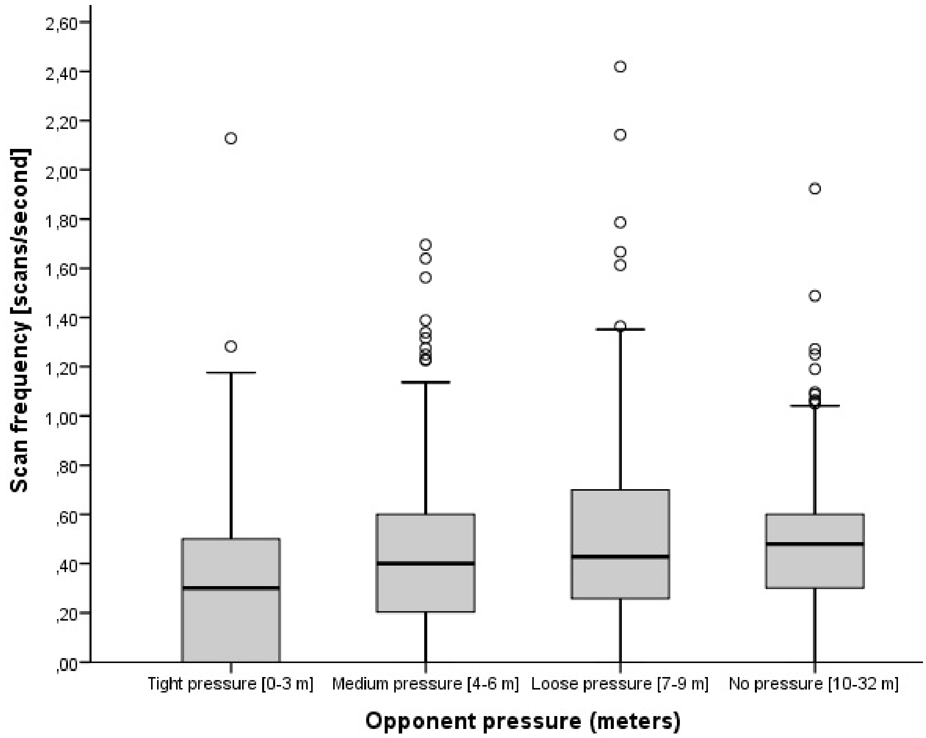

Figure 3. Boxplots (see Figure 2 caption for explanation of boxplot) of scan frequency according to opponent pressure (grouped).

Additionally, opponent pressure appeared to vary between different playing positions (see Table 3). However, these differences were not statistically significant, $\chi^2(2) = 8.19$, $p = 0.11$.

Table 3. Opponent pressure and playing position.

Playing position	Opponent pressure (m)		
	M	*SD*	*N*
Central defender	11.78	5.42	393
Fullback	7.54	5.31	376
Central midfielder	5.09	3.78	651
Winger	4.26	3.05	136
Striker	2.62	2.41	130
Total	6.94	5.36	1686

Furthermore, the results revealed that scan frequencies can vary based on the player's pitch position. On average, players who received the ball in one of the eight central areas (n = 946, M = 0.46 s/s, SD = 0.31) showed a higher scan frequency than players who received the ball in one of the eight outer areas (n = 740, M = 0.36 s/s, SD = 0.28), $t(1441) = 3.55$, $p < 0.001$, $d = -0.13$ (see Figure 4). This result supported our fourth hypothesis that wider pitch positions would lead to decreased scan frequencies.

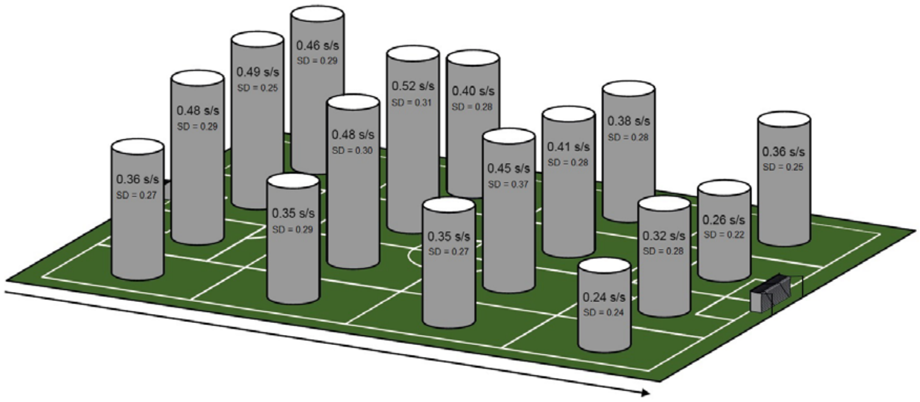

Figure 4. Mean scan frequency in the 16 different pitch positions (left to right from own half to opponent's half) with standard deviation values.

Playing position

In line with our hypothesis, the results revealed that central midfielders performed the highest mean scan frequencies (*n* = 651, *M* = 0.48 s/s, *SD* = 0.33) followed by central defenders (*n* = 393, *M* = 0.46 s/s, *SD* = 0.23), wingers (*n* = 136, *M* = 0.42 s/s, *SD* = 0.37), full backs (*n* = 376, *M* = 0.32 s/s, *SD* = 0.24), and strikers (*n* = 130, *M* = 0.27 s/s, *SD* = 0.26) (see Figure 5 for detailed boxplots including medians). The first set of analyses on scan frequency and playing position confirmed that players in different playing positions scan with different frequencies, $\chi^2(2) = 27.80$, $p < 0.05$. Subsequently, a Tukey post-hoc analysis was conducted. These analyses revealed significant differences between central defenders and fullbacks ($z = 0.14$, $SE = 0.02$, $p < 0.001$, $d = 0.6$), central defenders and strikers ($z = 0.18$, $SE = 0.03$, $p < 0.001$, $d = 0.9$), central midfielders and fullbacks ($z = 0.17$, $SE = 0.02$, $p < 0.001$, $d = 0.28$), central midfielders and strikers ($z = 0.21$, $SE = 0.03$, $p < 0.001$, $d = 0.3$), wingers and fullbacks ($z = 0.10$, $SE = 0.03$, $p < 0.01$, $d = 0.4$), and wingers and strikers ($z = 0.14$, $SE = 0.03$, $p < 0.001$, d

= 0.17).

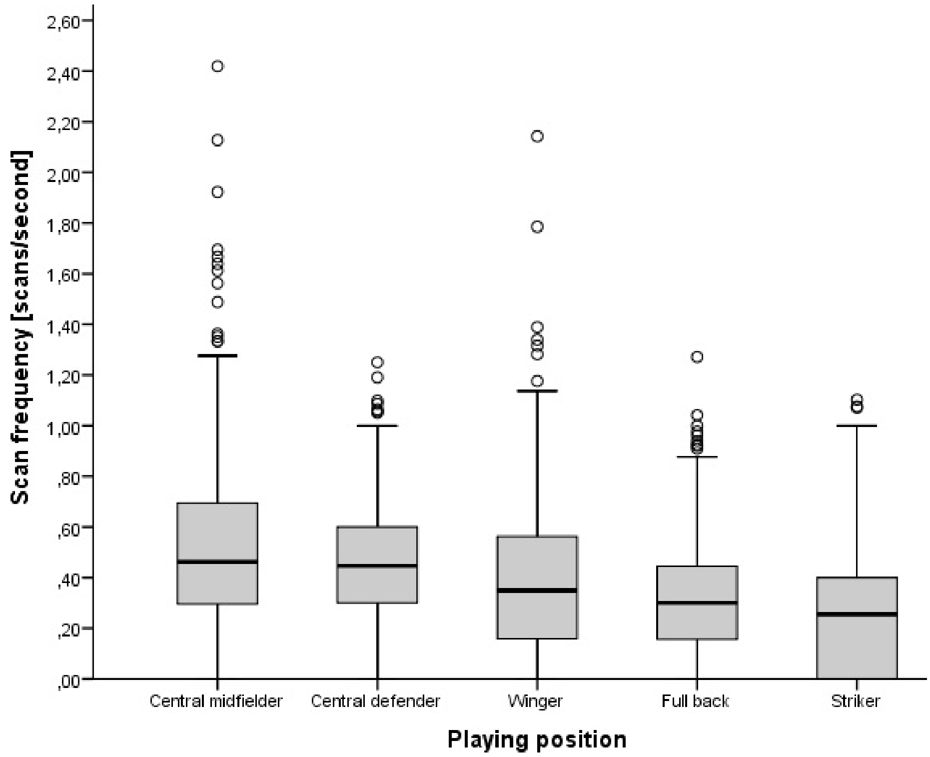

Figure 5. Boxplots (see Figure 2 caption for explanation of boxplot) of scan frequency according to the different playing positions.

Time from scan to ball contact

Finally, the timing of the players' scans was analyzed. Figure 6 displays the average duration between the different scans in sequential order prior to the player receiving the ball. For example, the average time onset of the last scan was 1.70 seconds (*SD* = 1.61) before receiving the pass. Only situations in which the player performed at least one scan were included in this analysis (n_{pass} = 1453).

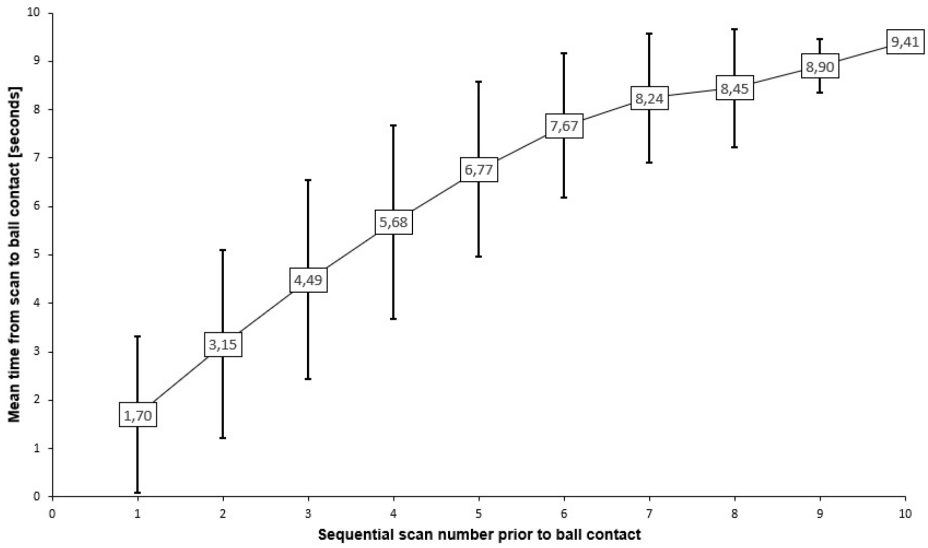

Figure 6. Mean time of the different scans in sequential order prior to receiving the ball with error bars representing standard deviations.

A linear mixed model revealed that the time of the last scan before receiving the ball differed significantly among U19 and U17 players (n_{pass} = 1453, $\chi^2(1) = 13.61$, $p <$ 0.001). U19 players (n_{pass} = 974) conducted their final scan an average of 1.59 seconds (*SD* = 1.52) before receiving the ball, whereas U17 players (n_{pass} = 479) performed their final scan an average of 1.92 seconds (*SD* = 1.77) before receiving the ball ($z = 0.33$, SE = 0.09, $p < 0.001$, $d = 0.2$). These results indicate that U19 players conduct their last scan before the first ball contact later than U17 players.

Discussion

The purpose of this study was to examine how the scanning behavior of some of the best elite youth football players in Europe related to players' performance, according to situational, context-specific, and temporal constraints, in the UEFA European U17 and U19 Championships semi-finals and finals.

In line with our first hypothesis, we found that the players who competed in the U19 Championship performed significantly more scans per second (scan frequencies) than players in the U17 Championship. This agrees with recent evidence showing that U23 players had a higher frequency of head movements compared to U13 players in the exploration phase before receiving the ball in a simulated football laboratory (Footbonaut) (McGuckian, Beavan, et al., 2020). Additionally, our findings show that the U19 players were able to conduct their last scans significantly closer to the moment they received a pass compared to U17 players. These results may be explained by the increased skill level and tempo demands relative to the players' age. Research has shown that the physical demands of U19 players are higher than those of U17 players (Rábano-Muñoz, Asian-Clemente, Sáez de Villarreal, Nayler, & Requena, 2019). Specifically, U19 players cover more distance and perform more sprints at different speeds than U17 players (Rábano-Muñoz et al., 2019). Thus, the increased spatial-temporal demands in U19 competition seem to force or encourage players to conduct more scans.

In the same vein, in line with the results showing that the higher level players (U19) in the current study had higher scan rates than the lower level players (U17), Jordet et al. (2013) showed that EPL players who had received an individual award had higher scan rates compared to those who had not. Studies conducted in laboratory settings have also found that more skilled football players look more frequently at locations away from the ball and ball carrier compared to less skilled players (Roca, Ford, McRobert, & Williams, 2011, 2013). Consequently, a focus on developing visual perceptual skills, such as scanning, increases with age and skill level and is important in youth and senior football players' performance.

In line with our second hypothesis, the data shows a positive relationship between scan frequency and overall pass result, as well as for forward-directed pass result only. These results reflect ecological psychology, which suggests that individuals who demonstrate the ability to explore their environment effectively and act upon appropriate information are thought to have a major advantage compared to others (Reed, 1996). It is plausible that when players scanned more, they were able to detect more passing opportunities (affordances) than when they scanned less and were therefore more often able to locate and send a pass to a teammate regardless of the opponent team’s effort in closing passing lanes. The significantly higher mean scan frequency when players completed their passes compared to when they missed has also been reported in some previous studies (e.g., Phatak & Gruber, 2019) but not in others (Eldridge et al., 2013; McGuckian, Cole, Jordet, et al., 2018). The increased number of game situations included in this study compared to most other studies makes it easier to detect significant differences in pass results, lending strength to the validity of our findings. In one of the latter studies (Eldridge et al., 2013), the low number of participants (three players) strongly limits the inferences that can be drawn. Moreover, our results substantiate previous findings in the literature, showing that increased scan frequency might be a contributing factor to positive changes in performance with the ball, such as turning with the ball (Eldridge et al., 2013), pass completion (Jordet et al., 2020; McGuckian, Cole, Jordet, et al., 2018), and attempting more forward passes (Jordet et al., 2013; McGuckian, Cole, Jordet, et al., 2018).

Our results also show that higher scan frequency before receiving a pass is related to players’ body orientation when receiving the ball. More specifically, significantly higher scan frequencies were found in players who received a pass with a forward or sideways orientation rather than a backward orientation. This result supports our third hypothesis and is in line with previous empirical results showing that exploratory actions are important when attempting to regulate movement prospectively (e.g., McGuckian et al., 2019). A sideways or forward position is the optimal body positioning for an attacking player to receive the ball, as this allows him to explore more affordances to attack quickly, subsequently directing an immediate action (i.e., dribbling or passing) toward the opponent's goal. A possible explanation for this result is that players use the information gathered from their extensive scanning behavior to see if there is space available for an immediate forward action. In comparison, players who explore less may be unable to detect the space to go forward and consequently choose the safer backward option. Comparably, our results show that players used more ball touches when they performed more scans prior to receiving the ball. A plausible explanation for these results is that higher scan frequencies provide players with a higher probability of performing the best future action with the ball, a concept referred to as prospective control (Montagne, 2005).

Similarly, we found that the closer players conducted their last scan to the time of ball reception, the more likely they were to be in a forward body position when they received the ball. Hence, the timing of the last scan before receiving the ball in attacking play appeared to be an important factor for subsequent performance with the ball. This is consistent with Phatak and Gruber's (2019) finding that midfielders in the 2016 European Championship made fewer turnover mistakes when they were able to perform more scans during the last pass before receiving the ball. By completing the last scan close to ball reception, players may increase their situational awareness of dynamically evolving game situations, more effectively solving threats and making the most of their opportunities for action.

In support of our fourth hypothesis, less time and space, here displayed by a decreased opponent pressure distance, influenced scan frequency negatively. Specifically, when players received the ball in tight situations (0–3 m), they exhibited lower scan frequencies compared to all other pressure situations. The same has been found for EPL players (Jordet et al., 2020). Unsurprisingly, this finding shows that when players have less space, they are more inclined to focus on the most important object, the ball, making sure that they do not lose it. In these instances, the players' focus may change from prospectively planning the next action after receiving the ball to making sure that the opponent will not be allowed to intercept the ball. Additionally, and also in line with our fourth hypothesis, we found that the players had significantly lower scan frequencies when they received the ball in one of the wide areas (outside of the 18–yard boxes) compared to one of the central areas. This supports previous findings in the literature (Jordet et al., 2020). These findings also match those of McGuckian et al. (2020), who found that central players turn their heads more frequently than wide players during attacking play.

In line with our fifth hypothesis, our findings revealed significant differences between playing position and scan frequency. We found that central midfielders and central defenders had higher average scan frequencies than all other playing positions. Additionally, wingers had higher scan frequencies compared to strikers. These results can be interpreted with respect to opponent pressure distance. For example, central defenders had, on average, much longer distances to their nearest opponents (11.78 m) compared to strikers (2.62 m) when receiving a pass. These results are similar to those of other studies in which loose pressure has been positively associated with more scans (Eldridge et al., 2013). Having more space and, consequently, more time means that players can look away from the ball without worrying about losing possession. However, tight pressure from opponents makes losing sight of the ball riskier.

In the present study, the higher scan frequency of central midfielders can be attributed to the competitive environment in which they are constantly surrounded by information. According to Gibson (1979), human beings use a head–eye system to gather information from ambient light, which can be understood as the structural lights surrounding an individual. Consequently, players situated centrally with opponents and teammates in every direction are “forced” to explore extensively due to the environmental constraints of the position. Comparably, the lower scan frequency of wingers and fullbacks can be explained by their frequent positioning near the sidelines, as important information is only found inside the pitch, not in all directions.

Practical implications

Based on our results, we propose some practical implications. Our results revealed significantly higher scan frequencies for players who participated in the U19 Championship compared to players in the U17 Championship. These results suggest that scan frequency increases with age and that there is an incentive to develop scanning behaviors in elite youth players (Pulling, Kearney, Eldridge, & Dicks, 2018). We, therefore, suggest that coaches look at scanning behavior as an integral part of player and team development, dynamically interlinked with physical, technical, and tactical development. From an ecological psychology perspective on skill development, scanning can be best developed through representative tasks practiced in game-specific environments to promote effective perception–action couplings (Renshaw, Davids, Newcombe, & Roberts, 2019). In addition, our results show that the requirements of scanning activity across different playing positions are different. Therefore, coaches need to create position-specific training exercises to enhance the scanning capabilities of players in different playing positions (Otte, Millar, & Klatt, 2019).

Limitations

Firstly, similar to other research on match analysis (Kubayi, 2020), a limitation of our study design is its inability to address the underlying mechanisms of scanning behavior and football performance. Secondly, we chose only to analyze ball possessions that ended up in an attempted pass. Thus, we might have excluded interesting information regarding the scan frequencies prior to other last actions such as dribbling and finishing. The inferences drawn from the study findings should, therefore, be interpreted cautiously. Future research is required to address whether the difference in the scanning behavior of U17 and U19 players demonstrated in our study is the result of deliberate practice or implicit adaptation to greater game demands.

Conclusion

In conclusion, our results illustrate how scanning behavior changes relative to different contexts (i.e., opponent pressure, pitch position), playing level (age), playing position, and receiving body position. Additionally, we found that higher scan frequency is associated with more successful forward passes and more successful passes overall. Future research is needed to investigate how scanning influences performance on different sub-scales, for example, by studying scanning activity in defense and at different ages and skill levels, and by developing more sophisticated measures of performance. Finally, experimental studies based on ecological psychology should aim to build upon our observational data to extend our theoretical knowledge and practice.

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Declaration of interest

The authors confirm that there are no financial, professional, or personal interests that could inappropriately influence the work presented in this article.

Data availability

The data used in this study is available upon request to the first author.

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Paper III

Aksum, K.M., Brotangen, L., Bjørndal, C.T., Magnaguagno, L. & Jordet, G. (2020). Scanning activity of elite football players in 11 v 11 match play: An eye-tracking analysis on the duration and visual information of scanning.

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Scanning activity of elite football players in 11 vs. 11 match play: An eye-tracking analysis on the duration and visual information of scanning

Scanning of elite football players: An eye-tracking analysis

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Scanning activity of elite football players in 11 vs. 11 match play: An eye-tracking analysis on the duration and visual information of scanning

Abstract

Visual perception in football (“soccer” in the U.S.) is increasingly becoming a key area of interest for researchers and practitioners. This exploratory case study investigated a sub-set of visual perception, namely visual exploratory scanning. The aim of this study was to examine the scanning of four elite football midfield players in an 11 vs. 11 real-game environment using mobile eye-tracking technology. More specifically, we measured the duration and information (number of teammates and opponents) of the players’ scanning behavior. The results showed that the players’ scanning duration was influenced by the ball context and the action undertaken with the ball at the moment of scan initiation. Furthermore, fixations were found in only 2.3% of the scans. Additionally, the results revealed that the stop point is the most information-rich part of a scan and that the players had more opponents than teammates inside their video frame during scans. Practical applications and further research recommendations are presented.

Keywords: eye tracking; visual exploration; elite; match play; football; perception; soccer

Introduction

Visual perception is crucial for performance across different sports [1]. More specifically, the moment (when) and location (where) of information gathering is regarded as imperative when attempting to explain athletic performance [2]. Our current knowledge of visual gaze behavior in sports, and football in particular, is primarily based on studies of eye-movement registrations in laboratory settings using eye-tracking equipment [3]. These studies have provided empirical knowledge about football players' gaze behavior through the examination of fixation durations, fixation frequencies, and fixation locations in different video-simulated tasks and viewpoints between participants of different skill levels (for a review, see [4]). For example, Roca et al. [5] found that participants in an 11 vs. 11 video scenario fixated their gaze differently when the ball was near to the viewpoint of a central defender compared to when it was far away.

In their review of visual perception in football, McGuckian et al. [6] found conflicting findings related to the visual perception behaviors of players at different skill levels and concluded that existing studies did not provide any clear evidence on differences in gaze behaviors. One reason for this may be the conditions of the studies, as football players' gaze behaviors have been shown to be different in laboratory studies than in more representative in situ studies [7]. This has recently led researchers to question the representativeness of the experimental tasks commonly used in studies of expert gaze behavior in dynamic sports, such as looking at screens, and how these translate to contextual sport performance [2]. Interestingly, only 31% of eye-tracking studies in high-performance sports have been conducted in the athletes' actual performance environment [2]. Therefore, Kredel et al. [3] argue that if the goal of a study is to examine gaze behavior in real-world conditions, the researchers should compromise on experimental control in favor of ensuring ecological validity. In order to bridge this gap, a recent study by Aksum et al. [8] investigated the fixations of five elite midfield players using eye-trackers in football match play and found that the players' fixation durations were much shorter than previously reported in laboratory studies. In sum, there is an apparent need for more research to be conducted in athletes' natural environments [2].

While the aforementioned branch of empirical research has focused on eye movements, another has adopted a more naturalistic approach to visual perception in football, with a focus on visual exploratory scanning, hereby referred to as scanning. This research methodology has examined visual perception in real match play at world-class levels, such as the English Premier League (EPL) [9, 10] and the European Championships [11]. Inspired by the ecological approach to visual perception [12], Jordet [13] suggests that in order to obtain enough information for performative football actions, players have to move their heads to direct the face (and eyes) away from the ball towards different sources of information, an activity referred to as scanning. In the ecological psychology framework, perception and action are coupled, reciprocal, and direct, meaning that human beings rely on extensive movement in order to perceive different opportunities for action [14]. According to Gibson, "We must perceive in order to move, but we must also move in order to perceive" [12]. To explain how an individual interacts with his or her environment by exploring and exploiting opportunities for action, the concept of affordances has been suggested [14]. Affordances are individual situational opportunities for action [15]. In football, affordances present themselves in all playing phases. For instance, affordances involving interaction with the ball rely heavily on the ability of players to explore their environment visually prior to engaging with the ball [16]. Thus, an ecological approach to visual perception provides us with a rich interpretive frame for investigating contextualized accounts of visual perception and movement behavior in real-world football match play. Furthermore, it greatly informed our research design because, according to the ecological approach, perception-action couplings are context-specific and have to be studied in the performance environment that the research aims to explain [17].

Visual scanning has been analyzed in a variety of field-based settings, including competitive matches [9-11], 11 vs. 11 training matches [18, 19], micro-states of play [20], and with the use of an individual pass training machine (Footbonaut) [21]. The results of these studies suggest that scanning is a contributing factor to the football performance of both youth [20] and elite players [9]. The most robust finding to date, which was found by examining 27 English Premier League players and almost 10,000 ball possessions, is that higher scan frequency prior to receiving the ball has a small but positive effect on subsequent passing performance [10]. Furthermore, scanning has also been shown to be susceptible to training with the use of imagery intervention programs [13, 22]. Additionally, one attempt was recently made to investigate scanning in a laboratory setting by placing four screens around each participant [16]. Results showed that higher head turn frequencies before “receiving” the ball resulted in faster decision-making when players “received” the ball [16]. However, none of the studies on scanning have attempted to investigate what football players *actually* look at when they conduct a scan. Hence, our method, using eye tracking on the pitch during match play, represents a groundbreaking alternative to the current research available on scanning. Lastly, all previous studies on scanning have either measured each scan subjectively, using match videos with somewhat low video resolution that makes it difficult to detect scans (i.e., [11]), or used inertial measurement units that capture head movement, but not in relation to the ball’s position (i.e., [19]). Consequently, the present study may be the first in which the objective detection and quantification of scans is possible.

Drawing upon these two different branches of research into visual gaze behavior in football, the current study is the first to investigate the scanning of elite football players in real match play using eye-tracking technology. As such, we aim to address the absence of field study research without restrictions [2]. In doing so, the aim of this exploratory study is to add to the knowledge of visual perception in football, particularly the duration and information of scanning behavior of elite players in different naturally occurring contexts. The study results have potential practical implications for researchers, coaches, and players alike.

Materials and methods

Participants

We recruited four male central midfield players, aged 17 to 23 (*M* = 20.75 years, *SD* = 2.87), who played for two different clubs in the Norwegian Premier League (*Eliteserien*). All players were part of the first-team squad of their respective clubs. In collaboration with the coaching staff of the respective teams, we selected players based on their position as central midfielders. This selection criterion was based on empirical data showing that central midfield players have higher scan frequencies compared to other playing positions [23], presumably because they are (more often than players in other positions) literally surrounded by multiple sources of information (the ball, teammates, opponents, etc.), which makes constant scanning activity essential for performance. As we aimed to study an elite sample, an additional inclusion criterion was that the player had to have played in the starting 11 of their respective team for more than one game. The players had, at the time of the data gathering, started between five and 71 matches (*M* = 38.25, *SD* = 26.09). One additional player, who was also part of the data collection, was excluded from the analysis based on this criterion to ensure that all players were in fact elite, consistent with previous scanning studies [23, 24]. Data from those five players' eye tracking records was also used in another study, which exclusively focused on the fixations of the players [8] compared to the current study, which exclusively looks at the scanning of the players. Written informed consent was obtained by all participants prior to data collection in accordance with the General Data Protection Regulation and the Declaration of Helsinki. The study was approved by the Norwegian Centre for Research Data (NSD), reference number 52593, prior to data collection.

Procedure

Both clubs were contacted via e-mail and telephone, and subsequent meetings took place between the clubs and the first and fourth authors. The dates for two separate data collections were agreed to by the coaching staff and the first author. Prior to the data collection, two pilot tests on elite youth players were conducted. These studies revealed the importance of attaching the eye-tracking battery in a secure and stable way and maintaining similar lighting conditions during the calibration and throughout the data sampling.

Data was collected during two 11 vs. 11 matches played with standard association football rules. One match was an internal training match within the squad, while the other was a friendly match against a local third division team. Data was collected during the competitive season of the two teams. At both matches, prior to the warm-up, the participants were each equipped with an eye-tracking device to allow them to familiarize themselves with the equipment and to ensure that a stable calibration was possible. This process lasted approximately three minutes for each participant. In total, two of the players were recorded for 20 minutes each, and two players were recorded for 10 minutes each. The difference in duration was due to (a) the match duration and (b) the duration of the fitting process. As this study does not analyze individual differences in any way, we decided to include all recorded data irrespective of duration.

Equipment

The eye-tracking device used to register gaze behavior when performing scanning was the Tobii Pro Glasses 2 (Tobii Technology AB, Sweden). The Tobii Pro Glasses 2 is a mobile binocular eye tracker operating at 50 Hz with four built-in infrared sensors catching the movements of each eye. It also contains a high-definition camera (1920 × 1080 px, 25 fps) with a minimum of 82° horizontal and 52° vertical detection, which films the visual scenery of the user. The glasses operate with a visual span of over 160° horizontally and 70° vertically according to the Tobii documentation [25]. The visual behavior was registered and stored by the Tobii Pro Glasses Controller version 1.73.8622 on a 32 GB memory card. The memory card was localized in a recording unit strapped onto each player's shorts or back, allowing him to move freely (see Fig 1).

Fig 1. The Tobii Pro Glasses 2 recording unit attached on the upper back of one of the participants. Printed with permission.

We also used a Panasonic AG-UX90 4K camcorder to film the match from a platform situated on the sideline approximately 5 m above the ground near the midfield line. Data from the camcorder was used to measure distances between players and the ball during scans when the ball would not be visible in the eye-tracking video. This ensured that the context could be accurately measured.

Variables

Based on Gibson’s conceptualization of exploration [12] and Jordet’s [13] operational definition of an exploratory search, we defined visual exploratory scanning (scanning) as an active head and eye movement away from the ball that temporarily causes the ball to fall outside of the participant’s visual field (eye-tracking camera). The player presumably performs this motion with the intention of looking for information from teammates, opponents, the referee, or space that is relevant to the development of play (see Fig 2).

Fig 2. Illustration of a visual exploratory scan directed from the ball’s position (far left) towards information to the left of the player (far right).

Only scans that were performed during open play were analyzed, with the exception of scans that were initiated within the two seconds leading up to a set-piece being taken, as this was viewed as an important time for information gathering. Additionally, in accordance with previous studies [23, 26], scans were only measured when the participants were not in possession of the ball. All scans detected from the four players were used in the analysis, totaling 869 scans (Player 1 = 381, Player 2 = 208, Player 3 = 177, Player 4 = 103). The data collection focused on two main properties of scanning as dependent variables: scanning duration and scanning information.

Dependent variables

Scanning duration was defined as the duration of scans in centiseconds (cs), as measured by Tobii Pro Lab (centiseconds are used as the time measurement scale throughout this paper as it provided us with the most accurate description of the results). Scanning duration was measured from the first video frame in which the ball was not visible inside the eye-tracking video to the first video frame in which the ball once again became visible. This operationalization was constructed to ensure maximum objectivity when measuring the start and end of a scan. The limitations of this operationalization were (1) micro scans in which the ball does not leave the video frame (these were excluded from the analysis) and (2) most scans start a few unequal numbers of centiseconds before our measurement starts.

Scanning information was the collective term for the number of players (i.e., teammates and opponents, respectively) visible during the scans (both foveally and in the scene camera). Scanning information was measured in three different ways. First, the number of players inside the entire video frame during the movement phases of the scan, which was defined as the number of teammates and opponents found inside the eye-tracking video frame during the two movement phases (away from and towards the ball), was determined. This excluded the number of teammates and opponents in the video frame at the stop point of the scan. This exclusion was made in order to not retain any overlapping data points between the number of players found in the entire video frame in the different moments of the scan (movement phases and stop point). Second, the number of players inside the entire video frame during the stop point of the scan was also measured. This was defined as the number of teammates and opponents found inside the video frame at the moment in which the player had the last stop point of the scan before moving his head and eyes back towards the ball. Third, the number of players found inside the foveal circle, measured at 100% in Tobii Pro Lab, during the stop point of the scan, was also measured. The stop point video frame was the last video frame before the direction of the scan was reversed.

Independent variables

With regard to independent variables, we measured those that provided additional context to the scanning duration and scanning information at the exact moment of the *initiation* of the scans. Four independent variables were used to provide further context for scanning duration: control or pass, air or pitch, ball action, and the presence of fixations.

The following operationalizations are made with reference to other players, as we did not measure scanning when the participants (the players equipped with eye-trackers) had possession of the ball. *Control or pass* refers to whether the scan was initiated when a player had control of the ball (either by touching it or between touches) or when the ball was on its path from one player to another. Control was defined as having the ball close to the player’s body after the initial receiving touch. *Air or pitch* refers to whether the scan was initiated when the ball was on the pitch (i.e., field) or up in the air. *Ball action* refers to the action that was undertaken with the ball at the exact moment the scan was initiated. This was divided into five categories: (a) receiving/dribbling touch, (b) during pass (the path of the pass), (c) out of play, (d) control, no touch (a player had possession of the ball, but it was between touches), and (e) moment of pass (touch). Lastly, to measure whether players foveally fixated on an object and/or space during their scanning, we measured the *presence of fixations* using the Tobii Pro Lab fixation filter set at a 120 ms threshold [27]. This threshold is similar to other gaze behavior studies in football conducted in laboratory settings [5, 28, 29], and it is in line with the 100–200 ms thresholds that are most frequently used in gaze behavior studies [30]. However, we argue that these threshold guidelines, originated from controlled laboratory settings, may not be able to accurately capture the shorter fixations that more likely occur in unrestricted field studies such as football match play. Thus, we included a supplementary data file in which the fixation threshold was set at 60 ms to make our data available for comparison for future analysis once a lower threshold has been accepted in the scientific community.

Additionally, two independent variables were analyzed in order to provide a scanning context in both scanning duration and scanning information: playing phase and player-to-ball-distance. The *playing phase* was split into attack and defense. Attack was operationally defined as the period when the investigated player's team had control of the ball; it ended when they lost possession to the other team, the ball went out of play, or a free kick was awarded [8]. Defense was operationally defined as the period when the investigated player's team did not have control of the ball; it ended when the opposition team lost possession to the investigated player's team, the ball went out of play, or a free kick was awarded [8]. We operationalized that a team had control of the ball when a player made two or more touches or was able to make a controlled pass or shot using his first touch. If neither team had control of the ball at the initiation of the scan, it was categorized as "other." *Player-to-ball distance* was defined as the number of meters between the analyzed player and the ball when a scan was initiated. This variable was subsequently divided into two groups: near (0–24 meters) and far (25–47 meters), based on similar previously used distinctions [5, 8].

Data analyses

The data analysis was conducted using Tobii Pro Lab (version 1.70.8207) and a split-screen synchronization of the video from the eye tracker and video from the camcorder, which was produced using the Sony Vegas Pro 13 program, and analyzed using the program Assimilate Scratch Play (version 9.2). Each scan was analyzed frame by frame in 50 frames per second (2 cs frame interval); there were a total of 869 scans. As the HD video camera attached to the Tobii Pro Glasses 2 eye-tracker only filmed at 25 fps (4 cs frame interval), synchronizing the video with our overview video (50 fps) made it possible to register scans at a 2 cs interval. However, this resulted in a higher number of scans being registered to end during odd frame numbers because every other frame would be blurry. The analysts were instructed to be certain that the ball had re-entered the video frame before registering the end frame of a scan.

In order to assess the reliability of the data, both an intra-observer and an inter-observer test were conducted on 10% of the complete dataset. The intra-test was conducted by the second author six weeks after the initial data analysis. The inter-test was conducted by a Union of European Football Associations (UEFA) B licensed coach with a bachelor's degree in sports science, who went through an intensive one-day training period to familiarize himself with the equipment and the variables. Cohen's kappa intra-observer strength of agreement [31] was perfect for the playing phase (k = 1), almost perfect for control or pass (k = .98), scanning initiation (k = .96), air or pitch (k = .92), and fixations (k = .94). Similarly, the Cohen's kappa inter-observer agreement was perfect for the playing phase (k = 1), almost perfect for control or pass (k = .94), scanning initiation (k = .96), air or pitch (k = .80), and fixations (k = .87).

Additionally, the intraclass correlation coefficient (ICC) was applied to measure the agreement of the scale variables [31]. The intra-observer test showed very strong agreement for player-to-ball distance (ICC = .99), teammates and opponents in the video frame during the movement phases of the scans (ICC = .97), teammates and opponents in the video frame during the stop point of the scans (ICC = .99), and teammates and opponents in the foveal circle during the stop point of the scans (ICC =

.96). Similarly, the inter-observer test showed very strong agreement for player-to-ball distance (ICC = .99), teammates and opponents in the video frame during the movement phases of the scans (ICC = .96), and teammates and opponents in the video frame during the stop point of the scans (ICC = .99), as well as acceptable agreement for teammates and opponents in the foveal circle during the stop point of the scans (ICC = .78).

Statistical analyses

Statistical tests were performed using SPSS 27.0 (SPSS Inc., Chicago, IL, USA). A Shapiro–Wilk test of normality showed that scanning duration significantly deviated from a normal distribution, $W(869) = 0.74$, $p < .01$, z (skewness) = 4.07, z (kurtosis) = 123.12. Consequently, we used non-parametric tests for all analyses in which scanning duration was used as a dependent variable. This included Mann–Whitney U tests for the analysis of the independent variables *control or pass* as well as *air or pitch* and a Kruskal–Wallis test for the analysis of the independent variable *ball action*. Additionally, Mann-Whitney U tests were used for *fixations in scanning*, *player-to-ball distanc*e, and *playing phase*. Regarding the three ways we used to measure scanning information (movement phases, stop point, and foveal circle stop point), ANOVAs were conducted for the number of players (teammates and opponents) with player-to-ball distance (near, far) and playing phase (attack, defense) as independent variables. Partial eta squares were calculated as effect size measures. The alpha level for all statistical tests was set *a priori* at $\alpha = .05$.

Results

Scanning duration

The players in this study performed 869 scans with a mean duration of 39.65 cs (0.3965 seconds) (*Mdn* = 34 cs, *SD* = 28.42, Max = 328 cs, Min = 2 cs). As depicted in Fig 3, 90.3% of all scans performed ranged from 2 to 66 cs, and the most common duration was 26 cs ($n = 95$).

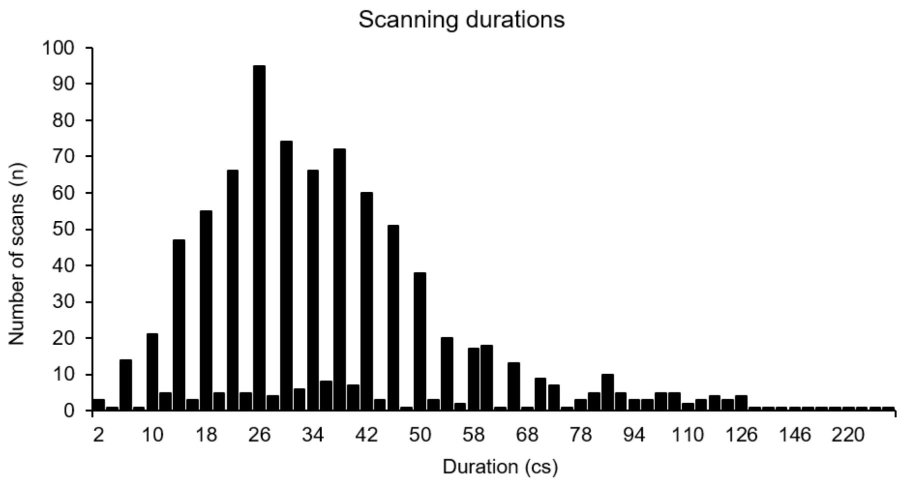

Fig 3. Number of scans as a function of different durations.

Scanning duration and ball context

Of the 869 analyzed scans, 835 were performed when the ball was on its path between two players (pass) or when a player had control of the ball. Initial analyses using a Mann–Whitney U test revealed that players had longer scanning durations when the ball was on its path (pass) ($M = 44.32$ cs, $SD = 30.62$, $n = 433$) than when the ball was under control (in possession) by a player ($M = 34.61$ cs, $SD = 24.95$, $n = 402$), $U = 67772$, $z = -5.54$ $p < .001$, $\eta_p^2 = .04$. In order to analyze the duration on scans initiated during different contexts further, we divided ball action into (a) receiving or dribbling touch;

(b) during pass (the path of the pass); (c) out of play; (d) control, no touch (a player had possession of the ball, but it was between touches); and (e) moment of pass (see Fig 4).

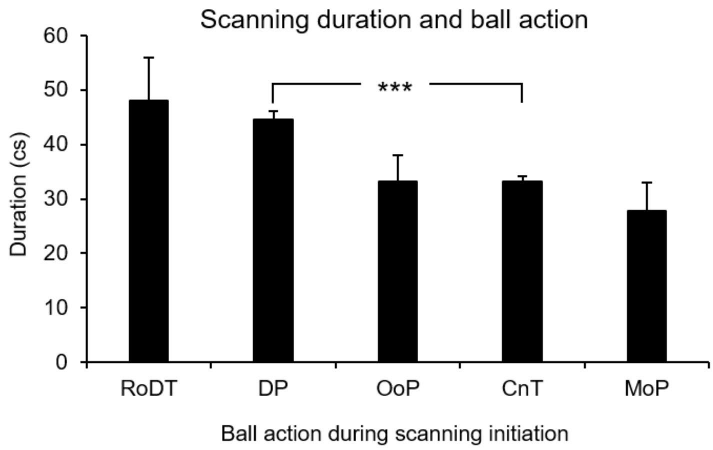

Fig 4. Means and standard errors of scanning duration during different ball actions: receiving or dribbling touch (RoDT); during pass (DP); out of play (OoP); control, no touch (CnT); and moment of pass (MoP).

A Kruskal–Wallis test revealed significant differences between the groups, $H(4) = 41.20$, $p < .001$. Post hoc, pairwise comparisons with adjusted *p*-values showed that significantly shorter scanning durations occurred when the ball was controlled by a player (without him touching it) compared to when the ball was on its path between two players after an executed pass ($p < .001$). No significant differences were found between the other groups. However, a trend was found suggesting that longer scans occurred during a receiving or dribbling touch compared to when the players had control of the ball without touching it ($p = .062$).

Additionally, we looked at the duration of scans initiated when the ball was up in the air compared to when it was on the pitch. A Mann–Whitney U test revealed a significantly higher scanning duration when the ball was in the air ($M = 45.24$ cs, $SD =$

35.45, n = 239) compared to when the ball was on the pitch (M = 37.54 cs, SD = 24.95, n = 630), U = 67343, z = -2.41, p = .016, η_p^2 = .01.

Scanning duration and the presence of fixations

Of the 869 scans analyzed in this study, only 20 (2.3%) involved a fixation (Player 1 = 5, Player 2 = 10, Player 3 = 3, Player 4 = 2) when using a fixation threshold of 120 ms. Initial analyses revealed longer average durations for scans that involved fixations (M = 97.10 cs, SD = 57.12, n = 20) compared to scans that had no fixations present (M = 38.30 cs, SD = 25.96, n = 849). A Mann–Whitney U test showed that scans that included fixations were significantly longer than scans that did not include any fixations, U = 2116, z = -5.76 p < .001, η_p^2 = .04.

Scanning duration, player-to-ball distance, and playing phase

To test the relationship between scanning duration, playing phase, and player-to-ball distance, we conducted separate Mann–Whitney U tests, using scanning duration as the dependent variable. The Mann–Whitney U tests revealed that there was no difference in duration between when the scans were conducted in the near (0–24 m) (M = 39.03 cs, SD = 27.37, n = 670,) and far (25–47 meters) conditions (M = 39.39 cs, SD = 25.13, n = 191,), U = 61648, z = -.77, p = .440, η_p^2 < .01. Furthermore, no difference in duration was found between defense (M = 41.15 cs, SD = 35.34, n = 341) and attack (M = 38.68 cs, SD = 22.86, n = 528), U = 88371, z = -.46, p = .65, η_p^2 < .01 (see Fig 5).

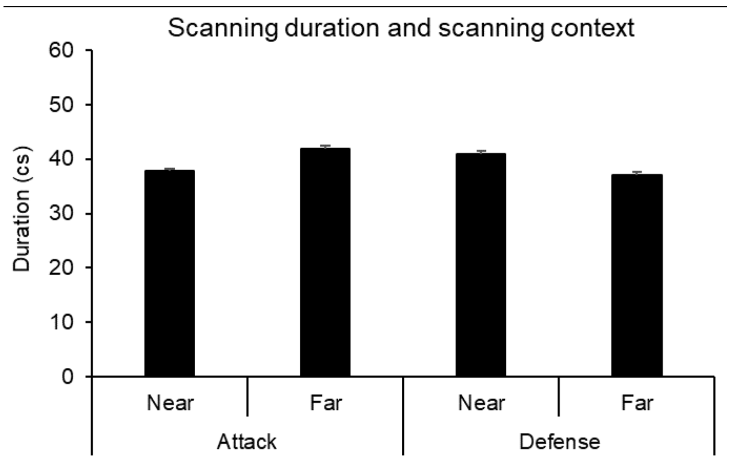

Fig 5. Means and standard errors of scanning duration as a function of playing phase (attack, defense) and player-to-ball distance (near, far).

Scanning information, player-to-ball distance, and playing phase

To assess scanning information, the first set of analyses investigated the number of teammates and opponents inside the video frame during the scans. Fig 6 compares the summary statistics of teammates and opponents according to the three ways of measuring scanning information we used in this study: movement phases (n_{scans} = 867), stop point (n_{scans} = 867), and foveal circle stop point (n_{scans} = 758). From the graph below (Fig 6), we can see that, in the movement phases of the scans, the players most often had zero teammates and opponents inside the video frame. This result should be seen in light of our operationalization of the movement phase which excluded all players that were visible inside the stop point of the scan. Furthermore, the players never had more than seven teammates; they did have both eight and nine opponents, although this happened infrequently. In contrast, the highest count found at the stop point of the scans was one to three players for both teammates and opponents.

Lastly, compared to the movement phases and the stop point, the foveal circle stop point of the scans showed a lower number of players (see Fig 6). For the foveal circle stop point, zero teammates and opponents were most frequently found. No more than two teammates and three opponents were inside the foveal circle during the stop point of the scans.

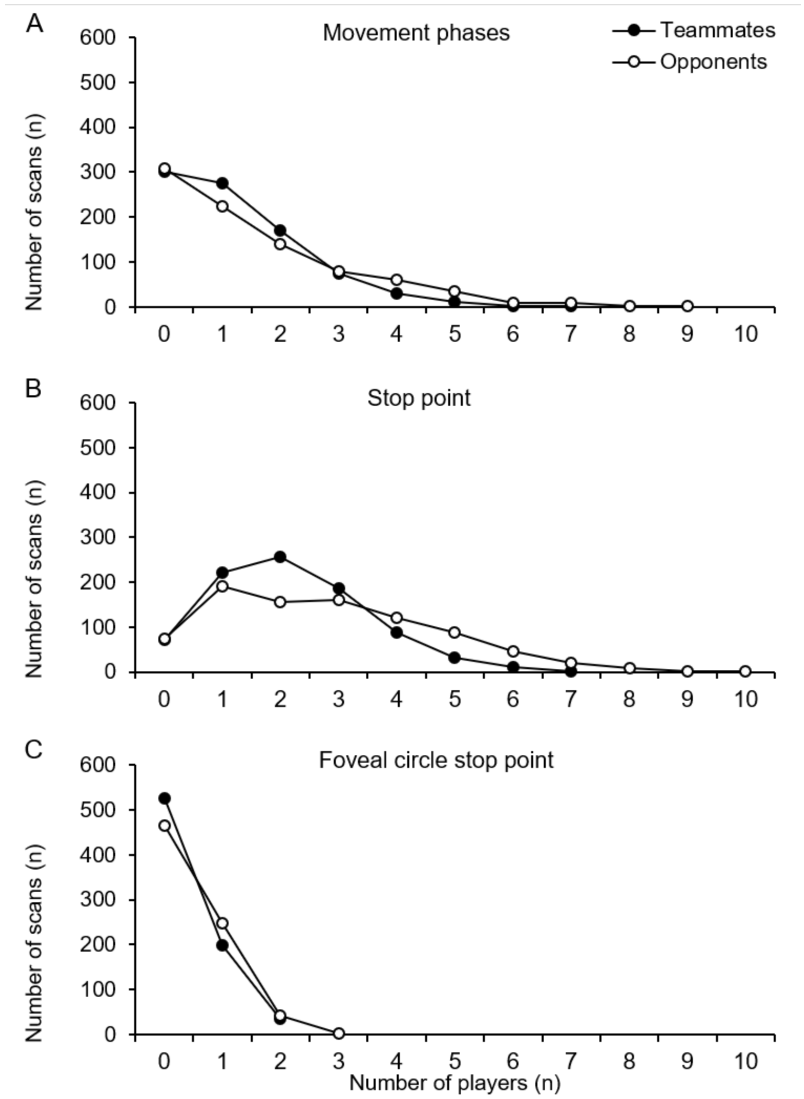

Fig 6. Number of scans on different numbers of opponents and teammates found in the video frame during the movement phases (A), the stop point (B), and the foveal circle stop point (C).

To assess how scanning information changes as a function of the playing phase and player-to-ball distance, a three-way ANOVA of the playing phase (2) × player-to-ball distance (2) × number of players (2), with repeated measures on the last factor, was conducted separately for the movement phases, stop point, and foveal circle stop point. For the movement phases, the analysis revealed a significant main effect for the playing phase, $F(1, 857) = 29.23$, $p < .001$, $\eta_p^2 = .03$, a significant main effect for number of players, $F(1, 857) = 28.68$, $p < .001$, $\eta_p^2 = .03$, and an interaction between the playing phase and the number of players, $F(1, 857) = 8.71$, $p = .003$, $\eta_p^2 = .01$. No other main effects or interaction effects were found.

These results show that during the movement phases of the scans, more players were found inside the video frame during attack than defense and that there were, in total, more opponents than teammates inside the video frame during the movement phases of the scans. More precisely, while on defense, no difference between opponents and teammates could be found. In attack, there were more opponents than teammates inside the video frame during their scanning behavior (see Fig 7).

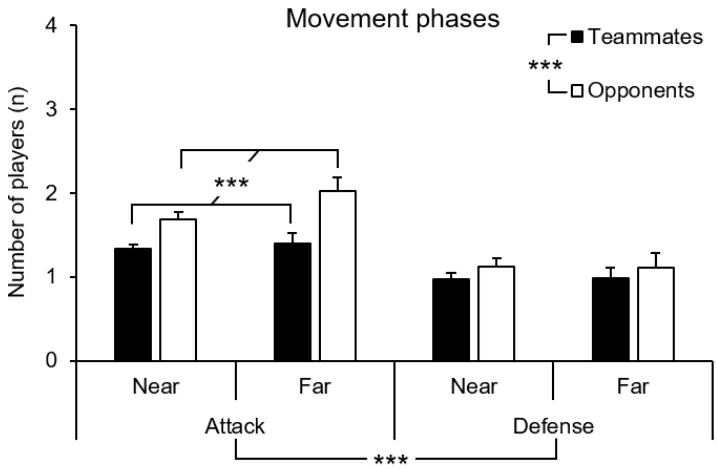

Fig 7. Means and standard errors of the number of teammates and opponents during the movement phases of the scans as a function of playing phase (attack, defense) and distance (near, far).

Similarly, the analysis for the stop point revealed a significant main effect for the number of players, $F(1, 857) = 50.39$, $p < .001$, $\eta_p^2 = .06$, and the interaction of the playing phase and number of players, $F(1, 857) = 31.95$, $p < .001$, $\eta_p^2 = .04$. However, there were no main effects for the playing phase, $F(1, 857) = 0.10$, $p = .747$, $\eta_p^2 < .01$, or player-to-ball distance, $F(1, 857) = 1.02$, $p = .204$, $\eta_p^2 < .01$, nor was there any other interaction. The finding that more opponents than teammates were found inside the video frame during the stop point only occurred during the attack phase (see Fig 8).

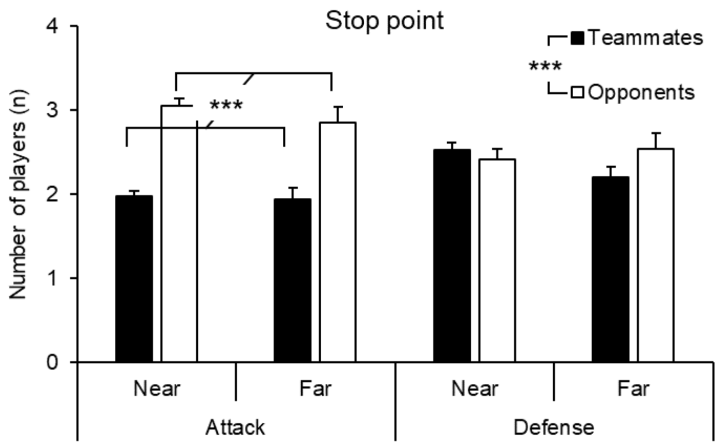

Fig 8. Means and standard errors of the number of teammates and opponents within the entire video frame at the stop point of the scans as a function of the playing phase (attack, defense) and distance (near, far).

For the foveal circle stop point, a main effect for the playing phase, $F(1, 747) = 7.32$, $p = .007$, $\eta_p^2 = .01$, and a significant main effect for the number of players were found, $F(1, 747) = 4.28$, $p = .039$, $\eta_p^2 = .01$. No other main effect or interaction was found. Again, more opponents than teammates were found inside the foveal fixation circle; however, there were significantly more players found in defense compared to attack (see Fig 9). This result was the opposite of what was found in the movement phases.

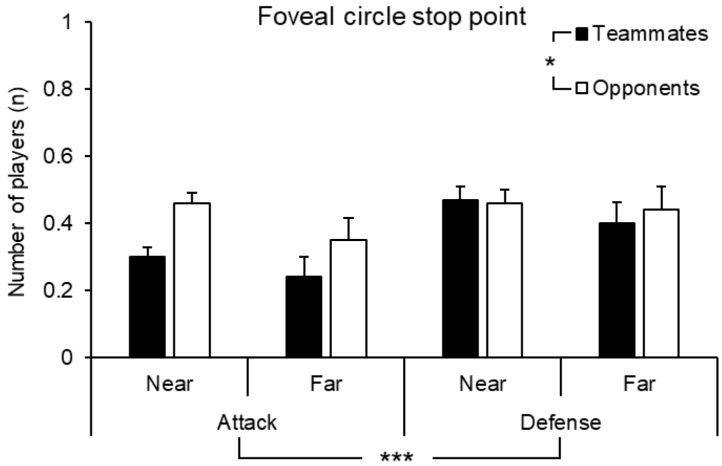

Fig 9. Means and standard errors of the number of teammates and opponents in the foveal circle of the stop point of the scans as a function of the playing phase (i.e., attack, defense) and distance (i.e., near, far).

Discussion

This study aimed to explore the scanning behavior of four elite football midfield players in 11 vs. 11 match play. More specifically, we wanted to examine the duration and information of scanning in different contexts using modern mobile eye-tracking equipment. The results of this study indicate that (a) the action undertaken with the ball at the moment of scanning initiation influences scanning duration; (b) playing phase and player-to-ball distance influence the number of teammates and opponents inside the video frame during scanning; (c) very few scans involve fixations; (d) based on our operationalizations, the different parts of a scan reveal different detectable visual information; and (e) scanning duration is not influenced by player-to-ball distance and playing phase. Given that our findings are based on a limited number of participants (four) from a homogenous population (elite midfielders), the results from our analysis, which will now be discussed, should be treated with considerable caution.

The first main and novel finding of this study is that scanning duration is influenced by the action undertaken with the ball at the moment a scan is initiated. In particular, the results showed that the players performed significantly longer scans when (a) the ball was in the air rather than on the pitch and (b) when the ball was passed between two players rather than when players had control of the ball but did not touch it (between touches). Both results suggest that the players in this study were more inclined to scan for longer durations, thus allowing them to gather more information when the future position and direction of travel of the ball could be more precisely anticipated. This main result also substantiates the notion from ecological psychology that perception and action are closely coupled (e.g., [12]), by showing how scanning behavior changes based on different action requirements and game situations.

In football, when the ball is being passed on the ground, the path and, consequently, the probable destination of the ball can be anticipated by skilled players (even more so when the pass is made in the air, where there is no one to intercept the ball). Performing scans with longer durations is logically similar to performing scans with bigger head excursions. Larger head excursions have been found to be indicative of better subsequent performance with the ball, such as faster passing responses [21] and the ability to switch play and turn with the ball [19]. It is therefore plausible that the players in this study were able to detect, based on the action on the ball, when it is possible to look away from the ball for longer durations (e.g., when the ball is in the air or the ball is on its path from one player to another) and when situations were more uncertain, requiring players to return their attention swiftly to the ball to achieve situational control (e.g., when the player has control of the ball but is not touching it). However, no previous studies have examined the durations of scans or head turns in relation to the action undertaken with the ball. Hence, these assumptions should be cautiously interpreted.

Second, the results showed no significant difference in scanning duration between the near (0–24 m) and far (25–47 m) distance conditions, suggesting that scanning behavior is not impacted by the player-to-ball distance. This finding was somewhat unexpected because previous studies on football with matching distance classifications have found that players' fixation durations are highly influenced by player-to-ball distance [5, 8, 29]. Although those studies did not measure scanning, they did look at sources of information for football players, making their results somewhat comparable to ours.

Similarly, our findings revealed no statistical difference between scanning duration in attack and defense. This finding is in agreement with McGuckian et al.'s [21] findings, which showed that there was no difference in head turn excursion between players in defense and attack (except by the player in possession) in both the vertical and horizontal pitch dimension analysis. This finding, while preliminary, suggests that the playing phase does not influence scanning duration, meaning that players perform scanning in a similar way in both attack and defense.

Our third main finding was that fixations were almost non-existent during the players' visual exploration, occurring in only 2.3% of the scans and only in scans with long durations. This result is highly interesting, as fixation properties are the most investigated aspect of gaze behavior in sports research to date [3]. The absence of fixations implies that players, when scanning, do not need to foveally fixate on the surrounding objects and spaces in order to acquire sufficient information for guiding their next action. Hence, when football players are looking for information away from the ball, the intake seldom originates from clear foveal information, which can only arise from fixations [32], but might instead be observed as colors and movements detected in the foveal and peripheral vision. This result may partly be explained by the fact that the adopted 120 ms threshold for fixation detection used in this study is not well applicable for real-world research, in which unstable and rapid movements occur all the time [8]. Thus, these data need to be interpreted with caution and show the need for investigating fixations during scanning in football further, preferably with a lower threshold. A suggested threshold of 70–80 ms would probably include more fixations for the analyses whilst maintaining a sufficient duration to account for the uncertainty of saccadic suppression (where information cannot be processed) [33] (see supplementary material for the analyses using a lower fixation detection threshold of 60 ms). Nevertheless, this key finding supports Gibson’s assumption that human perception should not be equated or compared to pictorial perception [12], during scanning.

Our fourth main finding was that, somewhat surprisingly, scanning durations were lower than expected. This result could be partly explained by our operationalization of a scan in which we started measuring the duration at the moment the ball left the video frame. Of all the 869 scans, 90.3% lasted for 66 cs or less. This is in agreement with Jordet’s [13] study of three elite midfielders, which found that so few scans lasted in excess of one second, referred to as long searches, that the results became inconsequential. In comparison, a recent study on scanning behavior in football using VR simulations focused on scans that lasted longer than one second, which the authors referred to as long exploratory activity [34]. While VR has the potential to create realistic simulations, our results show that scanning usually lasts much less than one second. Thus, once more, these results show that researching a real-world phenomenon, such as scanning, is problematic once we move outside of the actual performance context [35].

So far, this discussion has focused on scanning duration. The following section discusses the information that the players had inside their video frame when scanning. More specifically, the number of teammates and opponents visible during the scans in both the foveal vision and the scene camera. In the current study, the results from the foveal circle in the stop point of the scans showed that players had significantly more players inside their video frame in their foveal vision in defense than in attack. This result was not found in the movement phases or the entire stop point. Although eye-tracking devices cannot reveal where the user's attention is at a certain point in time [36], the foveal eye position is often similar to or the equivalent of attention [37]. Whether this attentional process relates to the conscious or self-organizing tendencies of movement control remains unclear and may have important implications for practice [38]. Furthermore, this finding suggests that the players in this study were more concerned with looking for the positioning of teammates and opponents in defense. In attack, they focused more on the open spaces that they could either exploit themselves, or use to play a pass into, if they received the ball. Whether this is related to strategy, shared intentionality, or the more generic properties of their skilled behavior remains unclear. One possible explanation is that the affordances (opportunities for action) available for the players change as a function of the playing phase because of the more dynamic structure of the attack compared to defense [39]. In attack, players might be looking for the spaces and gaps that are always opening and closing [39], whereas in defense, the play might be more structured, allowing the players to focus more closely on the player in possession.

Another important finding was that there were more visible players (both teammates and opponents) in the stop point of the scans than in the movement phases of the scans (away from the ball and towards the ball). It is, therefore, probable that football players move their heads and eyes until they arrive at a specific point where they wish to gather perceptual information before returning their attention to the ball. However, these differences can be explained in part by the fact that many scans were done with small head excursions; thus, the area in which the head was traveling in the movement phases was smaller than the area of the video frame at the stop point for these specific scans. Hence, these data must be interpreted with caution as they are a product of the operationalizations that was used in the current study.

In our study, we found that the players detected more opponents than teammates during their scans. This finding appears to be well substantiated: we found the same result in all phases of the scans. Thus, it is possible that the players in this study were more concerned with the movement and positioning of opponents than with their teammates when it came to gathering surrounding information. However, there are also two likely natural causes for these differences: (a) in football, it is possible to detect 11 opponents but only 10 teammates, and (b) the midfield players in this study, based on their pitch position, would often scan in the attacking direction where the opponent most often has numerical superiorities.

Limitations

Several limitations of this study must be acknowledged. First, although designs with few participants have been found to have high power and yield robust results [40], the study’s limited sample size, using exclusively midfielders, does not allow us to draw inferences regarding statistical generalizability. Second, the study design did not measure how scanning influenced players’ decision-making and performance, limiting the results to descriptive accounts. Third, our operationalization of a scan meant that small head movements when the ball was still visible inside the video scene camera (e.g., on the edge of the screen) were not included as a scan. In this way, we ensured that all scans were, in fact, scans. However, this also meant that some small excursion scans might have been excluded from the analysis. Fourth, the fixation threshold of at least 120 ms adopted in the current study has been the standard for gaze behavior research in sports conducted in both laboratory (e.g., [27]) and field-based studies (e.g., [36]) for decades. However, this threshold originated from laboratory studies in controlled settings with little to no movement [41]. Hence, adopting a lower threshold for fixation detection will include more fixations in the analysis and, thus, could be a better approach to combine measures of scanning and fixations in future real-world sports studies.

Practical applications

We believe that our findings, although exploratory and limited, may be useful to coaches who wish to improve their players' scanning behavior. Research has shown that although highly qualified coaches believe that scanning is vital for football performance, they find it difficult to deliver training on scanning [42]. First, most of the scans in this study were below 0.5 seconds and did not involve fixations (clear high-definition pictures[43]), supporting the notion that visual perception during scanning occur between the individual and the surrounding light and not the retinal image. This may suggest that coaches should consider creating exercises in which scans need to be performed quickly, in a dynamic affordance-rich environment. Coaches should limit their use of information that players need to fixate on during their scans in order to perform a task, such as counting the number of fingers the coach is presenting or reading a number on a sign. Coaches should likely instead strive to include a more representative perception–action link when training scanning skills in players [44]. Moreover, the scans conducted should probably be linked to a subsequent decision and action response, such as turning, passing, or directed dribbling.

Second, our combined findings that players had more opponents than teammates inside the video frame and that these numbers changed according to playing phase, during their scanning behavior, may imply that coaches should create practices that involve the detection of that particular type of information in order to be representative. Therefore, coaches should limit the delivery of unopposed exercises where football actions are made in the absence of opponents and/or playing phases. However, although the findings represent real world elite scanning behavior, it should not necessarily be mistaken for optimal behavior. Furthermore, with a small number of participants analyzed in a relatively small time period, caution must be applied, as the findings might not be representative of other populations in different football contexts.

Future research

The exploratory nature of this study highlights important areas for future research. Overall, future research should attempt to answer questions that originated from this study and build on the research method used to provide more knowledge of this under-investigated research area. First, studies should investigate differences in scanning duration and information between playing positions. We hypothesize that both the duration and information of scanning will be different across playing positions based on the different contextual limitations and performance tasks of these players. Second, studies should investigate the same differences in different age groups, genders, and skill levels. Third, studies should explore how different types of scans, such as scanning for orientation and scanning for action specification [45], influence behavior and performance because this might bring forward important practical implications. Finally, and most importantly, future research should aim to uncover *why* football players scan the way they do. Theory-driven research and mixed-method design that combines the eye tracking of players in 11 vs. 11 match play and subsequent game analysis interviews with the players may provide unique insights into whether scanning can be attributed to conscious or unconscious behavior.

Conclusion

The present study was designed to explore the duration and information of scanning in actual football match play at the elite level. The study findings suggest that the duration of scanning is influenced by the context of the ball as well as the action undertaken on the ball at the moment the player decides to scan. Furthermore, scanning duration does not seem to be influenced by playing phase or player-to-ball distance. The most surprising finding to emerge from this study is that only 2.3% of scans included fixations. An implication of this is the possibility that elite players do not see details when they scan: they only need to see the spaces, movements, and colors, which might have implications for how coaches should teach scanning. Furthermore, this study has shown that different parts of the scans show different types of information and that, in general, the players had more opponents than teammates inside their video frame during their scanning behavior. Hence, the scanning analysis in this study has extended our knowledge of how elite players explore their surroundings to gather information that is essential to their performance.

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Paper IV

Aksum, K.M, Magnaguagno, L., Bjørndal, C.T., Jordet, G. (2020). What do football players look at? An eye-tracking analysis of the visual fixations of players in 11 v 11 elite football match play.

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What Do Football Players Look at? An Eye-Tracking Analysis of the Visual Fixations of Players in 11 v 11 Elite Football Match Play

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Current knowledge of gaze behavior in football has primarily originated from eye-tracking research in laboratory settings. Using eye-tracking with elite players in a real-world 11 v 11 football game, this exploratory case study examined the visual fixations of midfield players in the Norwegian premier league. A total of 2,832 fixations by five players, aged 17–23 years (M = 19.84), were analyzed. Our results show that elite football midfielders increased their fixation duration when more information sources became available to them. Additionally, participants used shorter fixation durations than previously reported in laboratory studies. Furthermore, significant differences in gaze behavior between the attack and defense phases were found for both areas of interest and fixation location. Lastly, fixation locations were mainly on the ball, opponent, and teammate category and the player in possession of the ball. Combined, the results of this study enhance the knowledge of how elite footballers use their vision when playing under actual match-play conditions. They also suggest that laboratory designs may not be able to capture the dynamic environment that footballers experience in competition.

Keywords: football (soccer), perception, exploratory, ecological, experts, *in situ*, visual fixations

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INTRODUCTION

Visual perception in sport has attracted widespread interest from researchers and practitioners alike (McGuckian et al., 2018b). Research has generally shown that expert athletes have superior perceptual skills compared to non-experts (Mann et al., 2007). Specifically, expert athletes engage in more effective visual search strategies and focus on more relevant areas compared to less skilled athletes (Williams et al., 1999). This behavior has been replicated in a wide variety of sports and tasks, including football (Savelsbergh et al., 2002), tennis (Murray and Hunfalvay, 2017), handball (Rivilla-García et al., 2013), and volleyball (Piras et al., 2014). Expert athletes have also been shown to be more accurate in decision-making and faster in anticipating future events compared to less skilled athletes (Mann et al., 2007).

A fundamental prerequisite for visual perception is gaze behavior, which is thought to "optimize visual information processing which allows an optimal coupling between perception and action" (Klostermann and Moeinirad, 2020, p. 146). Gaze behavior research commonly distinguishes between smooth pursuits, saccades, pursuit tracking, and fixations (Duchowski, 2007).

Smooth pursuits describe the slow-movement tracking of an object; for example, following your finger as it slowly passes by your head while keeping your head still (Williams et al., 1999). A saccade is a very rapid, twitchy movement of the eyes from one position to another and can be understood as a transition between fixations (Schmidt and Lee, 2005). Although previous research has proposed that no information intake occurs during saccades (Duchowski, 2007), more recent research suggests that vision is clear and stable during saccadic eye movements (Binda and Morrone, 2018).

Fixations are especially central to understanding the gaze behavior that underpins sports performance. Fixations are eye movements that stabilize the retina over a stationary object and have been described as "pauses over informative regions of interest" (Salvucci and Goldberg, 2000, p. 71). The duration and location of these fixations vary depending on the type of sport and are used to extract relevant information for decision-making and action (Hüttermann et al., 2018). The ability to apply gaze fixations correctly is, therefore, highly relevant in dynamic team sports, such as football, where anticipation is integral to athletes' playing ability and skill level (Hüttermann et al., 2018).

An extensive number of studies reporting on gaze behavior in football have focused on the number, duration, and location of fixations in different video-simulated football scenarios conducted in laboratory settings (McGuckian et al., 2018b). Much of this research has attempted to investigate differences in gaze behavior between football players at different levels and experience. In their recent review of expertise-related differences in gaze behavior in sport, Klostermann and Moeinirad (2020) showed that empirical evidence on expertise-related differences in gaze behavior has declined in recent years with heterogeneous findings related to fixation duration and the number of fixations. The most prevalent finding relates to differences in gaze location and quiet eye duration (relevant for less dynamic sports or tasks), which was found to be longer for experts than intermediates and novices (Klostermann and Moeinirad, 2020).

Only a few studies have attempted to understand how visual fixations in football vary as a consequence of different task constraints (i.e., distance to the ball, attack v defense, number of players, and viewing perspective). For example, studies of simulated 11 v 11 play have shown that the number of fixations increases, the duration of fixations decreases, and the location of fixations is directed toward more objects of information when the ball is far from the player (Roca et al., 2013; Vater et al., 2016). When the ball travels closer, the location of gaze becomes more centrally focused toward the player in possession (PiP; Roca et al., 2013). Similarly, when players experience increased time constraints, they tend to focus their gaze centrally while using their peripheral vision to extract information from the positioning and movements of other players (Vaeyens et al., 2007). This type of gaze behavior is called a "foveal spot" (Vater et al., 2019). The main advantage of this type of gaze strategy is that information is processed faster peripherally, meaning that relying on peripheral vision in time-constrained situations might be advantageous (Vaeyens et al., 2007).

The representativeness of the experimental tasks has also been shown to influence the gaze behavior of athletes at different levels, with increased representativeness mediating expertise effects in gaze location (Klostermann and Moeinirad, 2020). For example, Mann et al. (2009) showed how viewing perspective influenced the gaze strategies of football players, where players spent more time observing open space and had more fixations of shorter duration from an aerial perspective than a playing perspective. The extent to which it is possible to transfer findings on gaze behavior in experimentally controlled situations to gaze behavior in real sports competitions remains unclear (Hüttermann et al., 2018). A reason for the limited representativeness is because it is difficult for experimental tasks conducted in laboratory settings to account fully for the dynamic performance context experienced by athletes (Pinder et al., 2011).

In football, actions are based on a complex array of visual, auditory, kinesthetic, and somatic senses (Headrick et al., 2015); particular task constraints, such as defensive pressure from opponents and position on the field (Pinder et al., 2015); and environmental constraints, such as different playing surfaces and weather conditions (Renshaw et al., 2019). Furthermore, in field-based studies, gaze behavior is not examined in isolation from the flow of motor movement or behavior, which may help develop knowledge about the coupling of perception and action (Hüttermann et al., 2018). There has, therefore, been a call by researchers to study gaze behaviors in environments representative of the specific performance context (Dicks et al., 2010; Eldridge et al., 2013; Klostermann and Moeinirad, 2020). Consequently, *in situ* designs using eye-trackers in mini-states of the respective sports have been conducted in basketball (van Maarseveen et al., 2017), ice hockey (Martell and Vickers, 2004), and futsal (Corrêa et al., 2020).

In an attempt to bridge this gap in football research, a recent study had 20 team sport athletes and 20 individual sport athletes perform a football-specific decision-making task using a motor response in front of an immersive screen (Hüttermann et al., 2019). Surprisingly, although the football players made more correct pass decisions, they did not show better attentional and perceptual performance compared to the participants from other team sports (Hüttermann et al., 2019). Although the study attempted to design an experimental task more representative of football performance, they used pictures of players on the screen and, in doing so, arguably failed to capture the dynamics inherent to the actual performance context.

Most studies conducted during real-world football match play have limited their focus to visual exploratory behaviors, such as the frequency of head movements (scanning) directed away from the ball (e.g., Jordet, 2005; Eldridge et al., 2013; Jordet et al., 2013; McGuckian et al., 2018a, 2020), neglecting the actual gaze behavior properties of football players, or restricting gaze behavior research to set plays (Klostermann and Moeinirad, 2020). In one of the few examples of field-based studies of gaze behavior in football, Nagano et al. (2004) reported the fixations of four experts and four novices in a 1 v 1 defense situation. They found that expert players conducted systematic visual search behaviors in which they fixated less exclusively on the ball compared to novice players. Nevertheless, the simulated game situation (1 v 1) was dissimilar to the spatial, temporal, mental, and physical demands that football players face during real competitive situations. To our knowledge, no study has examined the gaze behaviors of football players outside of standardized situations, more specifically during competitive 11 v 11 match play.

Based on this gap in the literature, this exploratory case study aimed to expand our understanding of the specific gaze behaviors of football players in a representative performance context. More specifically, we investigated the duration, location, and context of visual fixations of five elite-level football players in 11 v 11 match play. We collected data on gaze behaviors using modern eye-tracking technology in a real-world football context. The use of eye-tracking may provide a powerful balance between ecological validity and experimental control (Klostermann and Moeinirad, 2020). Furthermore, studying the gaze behavior of skilled athletes could provide unique insights into the underlying processes of complex movement behavior and provide valuable guidelines for practitioners, as well as a basis for further studies (Klostermann and Moeinirad, 2020).

MATERIALS AND METHODS

Participants

Five male football players, aged 17–23 years (M = 19.84, SD = 2.52), from two Norwegian premier league clubs, consented to participate in the study. All players were part of the first-team squad of their respective team, and all had played for Norway's under-21 national team, suggesting that they were regarded as being among the most talented players in their age group.[1] Participants were chosen based on their playing position as central midfielders. Players in this position are often surrounded by both teammates and opponents in every direction and are the most central players in attacking build-up play (Clemente et al., 2015), forcing these players to explore their surroundings constantly for optimal performance. The experiment was approved by the Norwegian Centre for Research Data (NSD), reference number 52593. All participants signed a written informed consent form in accordance with the General Data Protection Regulation and the Declaration of Helsinki prior to data collection.

Procedure

Data were gathered during the competitive season. The two teams that participated in the study were contacted by email and telephone. Subsequent meetings with the coaching staff of both teams were conducted by the first and fourth authors, and a date for the two separate data collection sessions was agreed upon. Two pilot studies on elite youth players were conducted in the weeks leading up to the first data collection session. These pilot studies revealed the importance of having somewhat similar lighting and weather throughout the entire data collection process. Fortunately, the agreed-upon dates featured favorable weather conditions, so that sunlight and rain did not negatively impact eye-movement detection.

Data were gathered during two training matches of 11 v 11 match play on a full-size pitch. Both matches were played on the training pitches of the two respective clubs. One of the teams played against a local third division team, while the other team played an internal training match consisting of players from the first-team squad. The matches were played with standard association football rules, and there were no coach interventions in either of the matches after the matches had started.

All players familiarized themselves with and tested the equipment prior to the warm-up. Before the data collection started, the participants donned eye-tracking units, so they could be fitted and calibrated individually. This process took about 3 min. Three players were recorded for 20 min, and two players were recorded for 10 min. The difference in the duration was due to (a) the duration of the match, (b) the duration of the fitting process, and (c) the battery from the eye tracker became detached from one of the players during play and had to be reattached and recalibrated. Because this study did not analyze individual differences, we decided to include all recorded data irrespective of duration.

Equipment

A Tobii Pro Glasses 2-eye tracker was used to assess the players' gaze behavior. The device consists of a head unit and a recording unit (see **Figure 1**). The camera on the head unit had a resolution of 1,920 × 1,080 at 25 frames per second. The recording unit was attached either on the player's shorts or upper back. This enabled the participants to move freely.

The eye-tracking device used in this study used gaze-overlaid video, meaning that the device recorded wherever the participant's point of gaze was fixed within the video display (Holmqvist et al., 2011). Thereafter, we used a fixation filter to look at all the fixations performed by the players. The Tobii Fixation Filter is a velocity-based algorithm for fixation detection in data as slow as 30 and 50 Hz. These velocity algorithms typically include smooth pursuits as fixations. Fixation velocity algorithms use a duration criterion in combination with a stillness criterion based on eye velocity to determine if a fixation or a smooth pursuit has occurred (Holmqvist et al., 2011).

Both matches were recorded with a Panasonic AG-UX90 4K Camcorder, stationed approximately 5 m above the ground right outside the touchline by the halfway line. The camcorder was used to triangulate the data with the eye tracker, specifically to measure distances between (a) the players and the ball and (b) the players and the nearest opponent.

Measures and Variables

In this study, we only analyzed fixations where the ball was in play. The only exception to this was fixations conducted within the 2 s prior to a set-piece being taken. This exception was included because it seemed likely that footballers also gather information in the few seconds leading up to the restarting of play.

Although fixations rarely last less than 100 ms (Salvucci and Goldberg, 2000), analyzing fixations with durations

[1]Since the data collection, all players in this study have established themselves in the squad of a Norwegian premier league team and have played between 33 and 137 matches (M = 86.2, SD = 42.16) at the top national level to date.

FIGURE 1 | The head unit (1) and recording unit (2) of the Tobii Pro Glasses 2. Printed with permission.

as low as 50 ms has been proposed as a possibility in mobile eye-tracking research (Holmqvist et al., 2011). For this study, however, in order to compare our results to other studies, we used a 120 ms minimum fixation threshold for inclusion (Williams and Davids, 1998; Roca et al., 2011, 2013).

Following the data collection, the eye-tracking videos from all the players were synced with the video from the overview camera using the program Sony Vegas Pro 13. We used the first visible ball reception contact to sync the videos. This resulted in a synchronized split-screen video comprising of an eye-tracking video (left) and an overview video (right). We then used the program Tobii Pro Lab to analyze all fixations. The program detected a total of 6,421 fixations. The data set was then reduced by removing fixations with durations of less than 120 ms (n = 3,388) and fixations that could not be classified as belonging to either the attack or defense phase (n = 201). Hence, 2,832 fixations were included in the final analysis.

Two measures of fixation properties were analyzed: fixation duration and percentage of viewing time. The former refers to the duration of a fixation in milliseconds, as measured by the Tobii Pro Lab fixation filter; the latter refers to the total viewing time spent fixating upon the different fixation locations (Vater et al., 2016). Furthermore, four measures of fixation context were used for the analysis: areas of interest, fixation location, playing phase, and player-to-ball distance.

Based on results from our pilot tests and previous research (e.g., Roca et al., 2013; Vater et al., 2016), four different areas of interest were identified: ball, opponent, teammate, and space. Areas of interest were defined as the exact object(s) of a fixation inside the gaze circle (set to 100% size in the Tobii Pro Lab), which were registered and coded (see **Figure 2**). For inclusion, the objects (i.e., ball, opponent, and teammate) had to be visible inside the circle. A fixation could, therefore, contain one teammate and one opponent. Furthermore, space was, to some degree, incorporated into most fixations, although fixations were only categorized as space when they were objectless (meaning when neither the ball, a teammate, or an opponent were visible inside the gaze circle, but parts of the pitch were). Fixations that did not fit any category were classified as other.

To further distinguish between what the players were fixating on, combinations of the four areas of interest were categorized, resulting in the following eight possible "fixation location" categories: ball, opponent, and teammate (B/O/T); ball and teammate (B/T); ball and opponent (B/O); ball (B); opponent and teammate (O/T); teammate (T); opponent (O); and space (S). This is a somewhat similar categorization to those of previous *in situ* designs (e.g., van Maarseveen et al., 2017) but differs from other previous laboratory studies (e.g., Roca et al., 2011). The reason for this difference is that, in contrast to laboratory studies where participants are asked to stand relatively close to a screen (for example, 2.8 m, Vater et al., 2016; 2.5 m, Roca et al., 2011, 2013; or 3 m, Hüttermann et al., 2019; away) and, therefore, aim all their fixations at the same exact screen regardless of distance, a real-world design means that all fixations are performed at pitch-level and at

FIGURE 2 | Picture of a gaze-overlaid video from Tobii Pro Lab. Printed with permission.

different distances. This results in fixations that frequently include more than one object. For example, if a player was looking at the PiP 20 m away, he might fixate on both the player's foot and the ball simultaneously. Similarly, if the player was looking at an opponent 10 m away, but there was a teammate right behind that player, situated 15 m away, both the opponent and the teammate would be part of the player's objects of fixation.

The measures of fixation context (i.e., areas of interest and fixation location) were conducted in two different playing phases: the attack phase and defense phase. The attack phase was operationally defined as extending from the moment the investigated player's team gained possession of the ball (by touching it) to the moment the ball went out of play, a free-kick was awarded, or possession was otherwise lost. When measuring fixation location in the attack phase, fixation on the PiP was considered equivalent to fixations that contained both teammate and ball. The defense phase was operationally defined as extending from the moment the opposing team gained possession of the ball (by touching it) to the moment where the ball went out of play, a free-kick was awarded, or possession was lost. When measuring fixation location in the defense phase, fixation on the PiP was considered equivalent to fixations that contained both opponent and ball. Hence, when referring to the B/T category in attack and B/O category in defense, PiP will be used.

Finally, we also distinguished fixations based on the player-to-ball distance. The player-to-ball distance was operationalized as the number of meters between the investigated player and the ball when a fixation was taking place. This variable was manually coded by the first author, who used the exact pitch markings and video from both the overview camera and the eye-tracker camera to ensure maximum precision. In order to compare the dependent variables under different conditions, a dummy variable was made based on the distance (meters) between the player and the ball. Based on the procedures used by Roca et al. (2013) and Vater et al. (2016) in which participants were situated approximately in the middle of their own half, and where every fixation conducted on the same half was considered to be in the near condition, we operationalized the near condition to be 0–24 m and the far condition to be 25–58 m.

In order to ensure reliable measures, we conducted both intra-reliability and inter-reliability tests for the near and far player-to-ball distance classifications as well as the areas of interest, on 142 (5% of the total) randomly selected situations. For the inter-reliability test, we used an experienced coder who had recently completed a Master's thesis on visual perception in football (and was a semi-professional football player at the time). The Kappa values of agreement for the player-to-ball distance were $k = 0.842$ ($p < 0.001$) for intra-reliability and $k = 0.881$ ($p < 0.001$) for inter-reliability, which is considered almost perfect agreement (Field, 2014). The intraclass correlation coefficient (ICC) for the areas of interest was 0.981 ($p < 0.001$) for intra-reliability and 0.987 ($p < 0.001$) for inter-reliability, again showing almost perfect agreement (Field, 2014).

Statistical Analysis

Statistical analyses were performed using SPSS 25.0 (SPSS Inc., Chicago, IL, United States). Differences between areas of interest, fixation location, and the distance condition on the percentage of viewing time and fixation duration for the defense and attack phase were analyzed using univariate analyses of variance (ANOVAs). Mean fixation duration of the eight fixation locations were determined for each participant. Bonferroni's corrections were used for comparisons of more than two groups, and Cohen's d was calculated as the effect-size measure. The alpha level for all statistical tests was set *a priori* at $\alpha = 0.05$.

RESULTS

Fixation Duration

The combined average fixation duration of all 2,832 fixations was 242.29 ms (*SD* = 195.03, *Min.* = 120 ms, *Max.* = 2,400 ms). In the attack phase, the average fixation duration was 247.07 ms (*SD* = 199.54, *n* = 1,486), whereas, in the defense phase, the average fixation duration was 237.02 ms (*SD* = 189.86, *n* = 1,346). A one-way ANOVA of playing phase (2) showed no significant effect, $F(1,2830) = 1.89$, $p = 0.171$, $d = 0.06$.

We also examined the average fixation duration for fixations conducted at different player-to-ball distances (*n* = 2,770, 62 missing). In the near condition (0–24 m), players had an average fixation duration of 228.55 ms (SD = 153.99, *n* = 1,853), whereas, in the far condition (25–58 m), players had an average fixation duration of 266.63 ms (*SD* = 249.54, *n* = 917). A one-way ANOVA of playing phase (2) revealed a significant effect, $F(1,2830) = 26.89$, $p < 0.001$, meaning that the players' fixation duration was longer in the far condition. However, the effect size of this result was very small, $d = 0.19$.

Number of Areas of Interest

The percentage of viewing time and the mean fixation duration for each of the informative areas of interest – featuring zero (open space), one, two, or three areas of interest (i.e., teammate, opponent, and ball) – were determined (see **Figure 3** for the percentage of viewing time). For the percentage of viewing time, the three-way ANOVA on areas of interest (4) × distance (2) × playing phase (2) with repeated measures on the last two factors revealed a significant three-way interaction [$F(3,16) = 5.65$, $p = 0.008$, $d = 2.06$], meaning that the interactions of the first two ANOVA factors differed across the playing phases. Consequently, two-way ANOVAs on areas of interest (4) × distance (2) with repeated measures on the last factor were conducted separately for each playing phase. For defense, the respective ANOVA revealed a significant effect for areas of interest [$F(3,16) = 134.53$, $p < 0.001$, $d = 10.06$] but not for distance [$F(1,16) = 0.00$, $p = 0.999$, $d = 0.00$] or the two-way interaction [$F(3,16) = 0.48$, $p = 0.698$, $d = 0.60$]. Pairwise comparisons with Bonferroni-corrected values of *p* showed significant differences for all comparisons (*p*s < 0.032), meaning that participants spent most of the time viewing two areas of interest, followed by three areas and one area of interest. Zero areas of interest (space) were very rarely fixated.

Contrarily, the two-way ANOVA on areas of interest (4) × distance (2) with repeated measures on the last factor for attack showed a significant effect for areas of interest [$F(3,16) = 130.94$, $p < 0.001$, $d = 9.93$] as well as an interaction effect [$F(3,16) = 5.25$, $p = 0.010$, $d = 1.98$], but no effect was discernible for distance [$F(1,16) = 0.00$, $p = 0.999$, $d = 0.00$]. Consequently, two separate one-way ANOVAs on areas of interest (4) were conducted for the near and far conditions. The analyses showed a significant effect for both the near condition [$F(3,16) = 72.58$, $p < 0.001$, $d = 7.40$] and the far condition [$F(3,16) = 53.47$, $p < 0.001$, $d = 6.32$], but no differences were observed for the Bonferroni-corrected *post-hoc* analyses.

In the near condition, significant effects were found for all comparisons (*p*s < 0.008) except for the difference between zero areas and one area of interest ($p = 0.058$). This result means that the participants spent the most time viewing two areas of interest followed by three areas of interest and, finally, one area of interest. The analysis of the far condition showed similar differences; however, no difference could be found between zero areas and one area of interest ($p = 0.999$), and the comparison of two and three areas of interest revealed no effect ($p = 0.999$). These findings imply that participants fixated more often on two or three areas than zero areas or one area of interest.

Table 1 reports the means and standard deviations for the fixation duration separated by distance and playing phase. The three-way ANOVA on areas of interest (4) × distance (2) × playing phase (2) with repeated measures on the last two factors revealed neither a three-way nor a two-way interaction [*F*s(3,13) < 2.98, *p*s = 0.071, *d*s = 1.66] as well as no effects for playing phase [$F(1,13) = 0.14$, $p = 0.713$, $d = 0.21$] and distance [$F(1,13) = 1.65$, $p = 0.221$, $d = 0.71$]. However, a significant effect was observed for areas of interest [$F(3,13) = 8.56$, $p = 0.002$, $d = 2.81$]. The Bonferroni-corrected pairwise comparisons demonstrated that the participants showed longer fixation durations for two and three areas of interest than zero areas of interest ($p = 0.007$ and $p = 0.003$, respectively). All significant findings for areas of interest revealed a large effect size, implying important differences.

Fixation Location

To examine gaze behavior, two three-way ANOVAs on fixation location (8) × distance (2) × distance (2) × playing phase (2) with repeated measures on the last two factors were conducted for the percentage of viewing time and fixation duration. The analysis of the percentage of viewing time revealed a significant three-way interaction [$F(7,32) = 2.66$, $p = 0.027$, $d = 1.53$], meaning that the interactions of the first two ANOVA factors differ across the playing phases. Consequently, two-way ANOVAs on fixation location (8) × distance (2) with repeated measures on the last factor were conducted separately for each playing phase. For both playing phases, the respective ANOVAs revealed significant effects for areas of interest [defensive phase: $F(7,32) = 81.86$, $p < 0.001$, $d = 8.45$; attacking phase: $F(7,32) = 114.56$, $p < 0.001$, $d = 10.06$], as well as three-way interactions [defensive phase: $F(7,32) = 2.36$, $p < 0.046$, $d = 1.44$; attacking phase: $F(7,32) = 6.42$, $p < 0.001$, $d = 2.37$]. However, no effects were noted for distance [defensive phase: $F(1,32) = 0.00$, $p = 0.995$, $d = 0.00$; attacking phase: $F(1,32) = 0.00$, $p = 0.999$, $d = 0.00$]. As depicted in **Figure 4**, participants spent most of their time viewing the PiP category followed by its B/O/T counterpart. This finding was independent of distance. However, the significant two-way interactions imply that the participants' gaze behaviors were different in the near and far conditions. Therefore, two separate one-way ANOVAs on fixation location (8) were conducted for each playing phase. For the defensive phase, the analysis showed a significant effect for both the near condition [$F(1,32) = 97.36$, $p < 0.001$, $d = 9.21$] and the far condition [$F(1,32) = 25.01$, $p < 0.001$, $d = 4.67$].

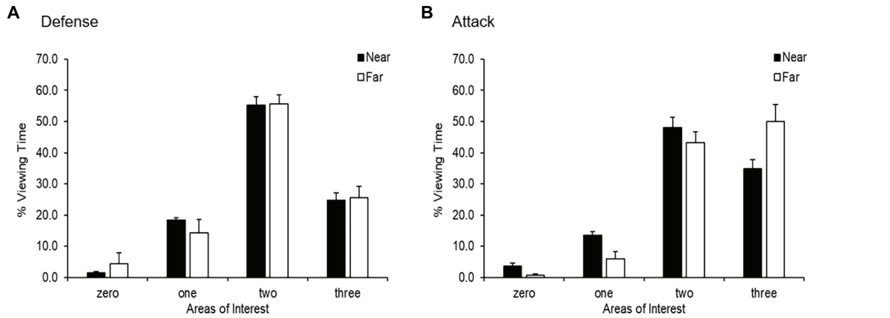

FIGURE 3 | Percentage of viewing time (*M* and *SE*) in defense **(A)** and attack **(B)** as a function of areas of interest (zero, one, two, and three) and distance (near and far).

TABLE 1 | Fixation duration (ms) on different areas of interest (zero, one, two, and three) as a function of distance (near and far) and playing phase (defense and attack).

	Near condition		Far condition		
	Defense	**Attack**	**Defense**	**Attack**	**Overall**
Areas of interest	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***
Zero	144.47 (12.10)	165.00 (28.43)	149.00 (32.42)	135.67 (9.81)	150.02 (23.80)*
One	201.01 (31.41)	190.80 (21.61)	216.50 (15.76)	182.00 (56.97)	197.39 (33.42)
Two	227.22 (26.25)	238.40 (27.75)	266.40 (51.37)	242.53 (52.39)	243.64 (40.69)*
Three	222.13 (23.18)	246.00 (26.60)	259.60 (110.75)	291.92 (22.99)	254.91 (60.21)*
Overall	198.71 (40.38)	210.05 (41.99)	227.33 (77.22)	223.96 (69.94)	214.33 (58.59)
	204.38 (41.06)		225.69 (72.71)		

*Significant differences (p < 0.05) are marked with *.*

In the near condition, the Bonferroni-corrected pairwise comparisons demonstrated significant differences between the B/O/T category and the PiP category ($p < 0.001$), as well as any other fixation location (ps < 0.001). Additionally, the participants spent more time viewing the opponent than the open space ($p = 0.023$). The findings for the far condition were similar. The analysis revealed that the participants fixated more on the B/O/T and PiP categories than any other fixation location (ps < 0.001), the results for the comparison between the B/O/T and the O/T categories being the exception ($p = 0.292$).

Besides these effects, one additional difference was found: the participants spent more time focusing on the O/T than the B/T category ($p = 0.031$). The effect sizes for all significant effects remained large, meaning that all the findings should be classified as important.

Similar to the defensive phase, the two separate one-way ANOVAs on fixation location (8) for attack showed significant effects for the near condition [$F(4,20) = 63.88$, $p < 0.000$, $d = 7.46$] and the far condition [$F(4,20) = 47.43$, $p < 0.000$, $d = 6.44$].

The Bonferroni-corrected *post-hoc* analysis for the near condition demonstrated significant differences between the B, O/T, and PiP categories and any other fixation location (ps < 0.001). Similarly, in the far condition, the Bonferroni-corrected pairwise comparisons showed that the participants spent more time viewing the B, O/T, and PiP categories than any other fixation location (ps < 0.001). However, no difference was found between the PiP and O/T categories ($p = 0.999$). Moreover, comparison between the B, O/T, and PiP categories also revealed an effect ($p < 0.001$). Additionally, the participants fixated more often on the O/T category than the B, O, B/O, T, or S categories (ps < 0.029). Similar to the defense phase, all significant findings showed a large effect size. Thus, these findings appear to be important.

Contrary to the analysis of the percentage of viewing time, the three-way ANOVA on fixation location (8) × distance (2) × playing phase (2) on fixation duration with repeated measures on the last two factors showed no three-way interaction [$F(7,23) = 0.73$, $p = 0.651$, $d = 0.94$]. However, a significant effect was found for distance [$F(1,23) = 4.60$, $p = 0.043$, $d = 0.90$], meaning that the participants exhibited longer fixation durations in the far condition than in the near condition. Additionally, the analysis revealed significant differences in fixation duration on fixation location [$F(7,23) = 3.76$, $p = 0.007$, $d = 2.14$] (see **Table 2**).

The analysis of the fixation duration revealed a significant effect for fixation location once again [$F(4,40) = 3.46$, $p = 0.004$, $d = 1.29$], but no interaction effect was observed [$F(4,40) = 0.34$, $p = 0.933$, $d = 0.40$]. Compared to the percentage of viewing time, a significant effect was found for distance [$F(1,40) = 5.97$, $p = 0.018$, $d = 0.64$], meaning that the participants showed longer fixation duration in the far condition than the near conduction (see **Table 2**).

The Bonferroni-corrected pairwise comparisons demonstrated three significant differences. The participants fixated on the B/O/T, PiP, and O/T categories longer than they did on space (S; $p < 0.001$, $p = 0.003$, and $p = 0.014$, respectively). Compared to the large effect size of the significant difference for fixation location, the finding for distance revealed only a medium effect size.

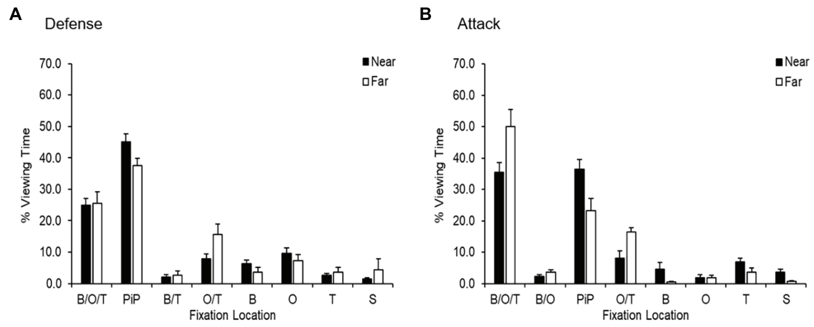

FIGURE 4 | Percentage of viewing time (*M* and *SE*) in defense **(A)** and attack **(B)** as a function of fixation location and distance (near and far). B/O/T, ball, opponent, and teammate; PiP, ball and opponent or ball and teammate; B/T, ball and teammate; B, ball; O/T, opponent and teammate; T, teammate; O, opponent; S, space.

TABLE 2 | Fixation duration (ms) on different fixation locations as a function of distance (near and far) and playing phase (defense and attack).

	Near condition		Far condition		
	Defense	**Attack**	**Defense**	**Attack**	**Overall**
Fixation location	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***
B/O/T	222.28 (23.08)	246.09 (26.58)	259.69 (110.82)	291.89 (23.09)	254.99 (60.21)*
PiP	233.53 (29.05)	254.82 (29.25)	281.82 (49.15)	246.14 (64.45)	254.08 (45.51)*
B/O; B/T	225.63 (58.54)	189.26 (17.19)	263.89 (86.76)	178.22 (39.49)	210.86 (59.44)
O/T	197.40 (35.25)	209.15 (36.01)	239.84 (87.15)	268.15 (59.91)	228.63 (60.74)
B	206.12 (43.52)	185.16 (16.91)	217.90 (70.77)	226.67 (150.11)	206.35 (67.47)
O	197.31 (27.25)	180.55 (51.14)	204.36 (21.92)	233.49 (101.95)	200.42 (50.64)
T	180.67 (49.01)	199.55 (26.31)	244.90 (46.44)	173.16 (40.92)	198.52 (46.43)
S	144.46 (12.11)	164.98 (28.40)	149.17 (32.59)	135.56 (9.62)	150.03 (23.83)*
Overall	200.29 (42.85)	203.69 (40.96)	235.07 (74.78)	224.29 (77.10)	214.89 (61.16)
	202.01 (41.67)**		229.84 (75.54)**		

*Significant differences (p < 0.05) are marked with * and **. B/O/T, ball, opponent, and teammate; PiP, ball and opponent (defense) and ball and teammate (attack); B/O, ball and opponent (attack); B/T, ball and teammate (defense); O/T, opponent and teammate; B, ball; O, opponent; T, teammate; S, space.*

DISCUSSION

This study was conducted to learn more about the gaze behaviors of elite football players in a real-world performance setting. We analyzed a total of 2,832 fixations from five players during two training games and focused our analysis on the duration and location of fixations during 11 v 11 match play.

The most striking result from our analysis is that these elite footballers used longer fixation durations when more areas of interest (i.e., ball, teammate, and opponent) were visible in their foveal vision (fixation circle). More specifically, the players performed significantly longer fixations when there were two or three areas of interest compared to zero areas in the attack phase and compared to both one and zero areas in the defense phase. These results run contrary to those of Helsen and Starkes (1999), who reported that players reduce the duration of their fixations when more display information becomes available. However, other studies of gaze behavior have shown that fixation duration increases with more information (Just and Carpenter, 1976).

Our findings suggest that the more complex the situation (i.e., being positioned between opponents' lines of defense), the more time the player may need to obtain sufficient information before executing his decision. Interestingly, these results were similar regardless of whether the ball was near (0–24 m) or far from the players (25+ m). Hence, the number of areas of interest seemed to have a larger impact than player-to-ball distance on fixation duration in real football match play.

The observed association between fixation duration and areas of interest of the central midfielders in this study should be viewed in light of their positional demands. Research has shown that central midfielders are the priority link in attack play in football (Clemente et al., 2015). Central midfielders have been shown to have the highest number of passes and pass accuracy of any playing position (Bradley et al., 2013). Consequently, players in that position are used to expecting the ball in different areas and phases of play and have, therefore, learned to look for opportunities for action in ways specific to their playing position.

The present study also found that the average duration of fixations was significantly shorter than expected based on prior studies conducted in a laboratory setting. Our results revealed that players had an average fixation duration of 242.29 ms. Different laboratory studies on elite or skilled footballers, deploying similar fixation thresholds, have reported average fixation durations ranging from 467 to 1,002 ms (Helsen and Starkes, 1999), 423 to 492 ms (Mann et al., 2009), 369 ms (Roca et al., 2011), and 332 to 598 ms (Roca et al., 2013). These discrepancies raise the question of whether examining football players' visual fixations in a laboratory setting is inadequate when attempting to capture footballers' gaze fixations during the dynamics of match play, where a different landscape of information and sensations influence both decision-making and gaze behavior (Hüttermann et al., 2018).

The same differences in duration were also evident when comparing the mean fixation duration from our study to *in situ* experiments in other sports, such as basketball (342–677 ms; van Maarseveen et al., 2017) and ice hockey (346.74 ms for elite and 591.59 ms for non-elite; Martell and Vickers, 2004). A possible explanation for this might be that the experimental tasks and study context focused on different, specific game situations of each sport: 2 v 2 (Martell and Vickers, 2004) and 3 v 3 (van Maarseveen et al., 2017). The time and spatial constraints may vary depending on game situations and sports, which may limit gaze behavior to fewer potential fixation locations than in our study.

Another possible explanation for the shorter fixation durations found in our study could be the high skill level of the participants. The participants were elite players, playing at the highest national level. Similarly, both Williams et al. (1994) and Cañal-Bruland et al. (2011) found that experienced football players used shorter fixations than inexperienced players, which could be attributed to the quicker and more precise information extracting ability of elite players (Cañal-Bruland et al., 2011). Following this argument, it is possible that a comparison of lower-level and elite players in more representative settings would provide similar results because lower-level players may need more time to draw information from each fixation compared to experts (Williams et al., 1994).

Another important finding was the relationship between areas of interest and the percentage of viewing time. As seen in **Figures 3A,B**, a reverse-U shape appears in the defense phase as well as in the near-condition attack phase. Conversely, the results show a progressive increase in percentage viewing time in the far condition attack phase. This raises the question of whether the player-to-ball distance has a bigger influence on gaze behavior in the attack phase than in the defense phase. This result may be explained by the fact that when the ball is far from the players in the attack phase, they direct their attention to sources of information other than the PiP in the search for space to exploit for themselves or their teammates, thus fixating on more areas of interest. However, when the ball comes closer and the opportunity to receive a pass increases, they direct their attention to the PiP.

In the current study, an examination of the players' viewing time of fixation locations in the defense phase revealed that they focused their visual attention on the PiP category significantly more than any other category. This effect was prevalent in both the near and far conditions. This result is even more sizable than reported since the B/O/T category often includes the PiP category as well. This finding is similar to the results reported by Roca et al. (2013) and Vater et al. (2016), who found that players fixated significantly more on the PiP than any other fixation locations in the defense phase.

Interestingly, analysis of players' viewing time in the far-condition attack phase revealed that the participants spent 49.99% of the time fixating on the B/O/T category. This was significantly more than any other fixation location in the far condition. This result may be explained in part by the long distance (25 m+), which makes it more likely that additional objects will appear in the line of foveal vision between the ball and the analyzed player. However, the same effect did not occur in the defense phase. The B/O/T category is a new fixation location category, constructed especially for our natural environment study context; therefore, more research is needed to understand why players fixate foveally on this category to such a degree when the ball is far away in the attack phase.

Finally, the fixation time given to the O/T category in attack was shown to be significantly higher in the far condition compared to the near condition. Although not significant, the same tendency was found in the defense phase. It is difficult to suggest a tentative interpretation of this result since this is the first study to utilize an O/T fixation location category. However, a plausible explanation may be that when the ball is further away, players have more time to look at more informative areas away from the ball in order to detect important information that may guide future defensive and attacking behavior. This activity has previously been reported as visual exploratory behavior (McGuckian et al., 2018a).

Previous research has shown that elite midfielders have an exploratory frequency of up to 0.62 per second in the 10 s leading up to receiving the ball (Jordet et al., 2013). It is, therefore, reasonable to believe that the elite midfielders in this study also performed extensive visual exploratory behaviors in the attack phase, especially when the ball was far away. To investigate this further, studies that combine measures of gaze and visual exploratory behavior are needed.

Our findings suggest some practical implications for coaches and athletes. For example, we found that the average duration of a fixation in real-world football is quite short (242.29 ms), suggesting that numerous quick fixations are relevant to seizing opportunities for action provided in the game environment. Additionally, our results suggest that increasing the number of informative areas in the display, from only searching for space (S) to looking for the ball, opponents, and teammates (B/O/T) simultaneously, increases the time needed to draw information from those sources. Thus, exercises should provide players with the ability to locate many sources of information under severe time constraints, inducing the same dynamics prevalent in the players' use of their visual perceptual systems representative of real-world match play. For example, there is less need for longer fixations in a 2 v 2 situation than an 8 v 8 situation because there are fewer potential areas of interest present. Closed drills where movement solutions are pre-determined, conducted in an environment that is non-representative of the match-play context, might alter the visual fixation and search strategies football players use in 11 v 11 match play. In sum, coaches need to be aware of how visual fixation and search strategies change depending on the numerical, spatial, and temporal conditions of an exercise.

LIMITATIONS

The findings of this study should be considered in light of some limitations. First, the study was explorative and observational, preventing us from addressing any causal relationships and restricting the generalizability of our results. Our implications for practice should, therefore, be considered tentative and speculative and may be contested by future experimental research. Second, the lack of a clear theoretical framework limited our ability to generate and test clear hypotheses. Third, we chose not to include measures of decision-making and performance in this study, instead focusing solely on players' gaze behaviors. Fourth, the manner in which the dynamics of the game influenced gaze behavior, for example, if a team scored early on, was not controlled for. Having a lead would potentially direct the gaze toward more defensively important aspects of the game, thus influencing our results. Fifth, our *in situ* design did not allow us to include any measure of fixation frequency. Because of the study context, where all players experienced completely different playing situations, played a different number of seconds in the attack and defense phase, and had a different number of gaze samples, the inclusion of any measure of fixation frequency would not constitute a valid approach. Finally, inaccuracies in the technological equipment's detection may have occurred due to the limited use of head-mounted eye-tracking devices in real-world football matches prior to our study.

FUTURE RESEARCH

Based on the limitations and results of this study, we propose several recommendations for future research. First, future research should address how performance is associated with gaze behavior in football, such as passing accuracy (Eldridge et al., 2013) or defensive actions (Nagano et al., 2004). Second, future research across all invasion sports should replicate our study design in order to investigate differences in gaze behavior between players at different skill levels. Third, future research should explore methods of simultaneously examining foveal and peripheral vision. Fourth, future studies should examine different playing positions and strategies because there is reason to believe that players in positions other than central midfielders utilize different gaze behaviors (McGuckian et al., 2020). Fifth, studies should strive to combine measures of gaze and visual exploratory behavior. This is because it is reasonable to believe that the elite midfielders in this study also performed extensive visual exploratory behaviors in the attack phase, especially when the ball was far away, similar to the exploratory frequencies reported by Jordet et al. (2013). Sixth, future research could benefit from positioning itself within a clear theoretical perspective in order to generate and test hypotheses relevant to promoting an understanding of how visual perception underpins sports performance.

CONCLUSION

In recent years, the association between gaze behaviors and performance has received extensive interest from researchers and practitioners. With the use of new technologies, we now have the opportunity to investigate the gaze behaviors of football players during match play. Our exploratory case study reported differences in both the areas of interest and fixation locations when the ball is near or far, as well as when playing in the attack or defense phase. The average fixation duration was lower than previously reported in laboratory-based research designs, as well as *in situ* designs in other sports. Furthermore, the results revealed that elite central midfield players have a longer fixation duration when more areas of interest are available to them.

DATA AVAILABILITY STATEMENT

The data generated for this study are available upon request to the first author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Norwegian Centre for Research Data. The participants provided their written informed consent to participate in the study.

AUTHOR CONTRIBUTIONS

KMA contributed to the conceptualization, data collection, data analysis, and writing of the paper. LM contributed to the data analysis and writing of the paper. CTB contributed to parts of the data analysis and writing of the paper. GJ contributed to the conceptualization, data collection, and writing of the paper. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any personal or financial relationships that could potentially be depicted as a conflict of interest.

Appendix A

Letter of consent for Paper III and IV

Forespørsel om deltakelse i forskningsprosjektet

"Visual exploratory behaviour (VEB) in 11 vs 11 football matchplay: A Tobii eye tracker analysis of positional requirements"

Bakgrunn og formål
Formålet med studien er å kombinere bruk av videobriller med videofilm av kampen for å undersøke eksakt hvilke visuelle søksprosesser sentrale midtbanespillere benytter seg av i kamp. Prosjektet er en del av min doktorgradsavhandling om visuell persepsjon i fotball ved Norges Idrettshøgskole.

Et nytt, men lignende formål, er å kun se på spillernes søk ved bruk av det samme datamaterialet. Hensikten med det er å undersøke hvor spillere ser når de utfører søk (visuell eksplorerende atferd). Denne delen av prosjektet er en del av Lars Brotangens masteroppgave ved Norges Idrettshøgskole.

Du/Dere er valgt ut med bakgrunn i at dere er del av et lag som spiller på et nivå som er godt nok, og dere har en alderssammensetning som passer til studien.

Hva innebærer deltakelse i studien?
Som deltaker i denne studien skal du benytte deg av videobrillene Tobii eye tracker under kampsituasjon. Du vil være nødt til å ha på deg brillene i cirka 15 minutter i en kamp. Videoen som genereres fra brillene vil benyttes i forskningen. Det vil også bli tatt video av selve treningskampen. Det vil også samles inn noe fotballstatistikk om spillerne som deltar i prosjektet.

Hva skjer med informasjonen om deg?
Alle personopplysninger vil bli behandlet konfidensielt. Kun meg selv, veileder Geir Jordet, og masterstudent Lars Brotangen vil ha tilgang til dataene i prosjektet. Ingen informasjon eller video av deg vil bli benyttet utover dette prosjektet. Du vil ikke bli gjenkjent i publikasjonen.

Prosjektet skal etter planen avsluttes 31.12.2018. Alle innsamlede data anonymiseres, og videoopptak slettes, senest ved prosjektslutt.

Frivillig deltakelse
Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert.

Dersom du ønsker å delta eller har spørsmål til studien, ta kontakt med Karl Marius Aksum 95974819.

Studien er meldt til Personvernombudet for forskning, NSD - Norsk senter for forskningsdata AS.

Samtykke til deltakelse i studien

Jeg har mottatt informasjon om studien, og er villig til å delta

----
(Signert av prosjektdeltaker, dato)

Appendix B

Information letter to national team coaches (Paper II)

Participation in a research project

"(Visual search analysis of football players competing in the Under-17 and Under-19 European Championships)"

This is an orientation from myself to you regarding the participation of your players in a research project, where the goal is to investigate visual search behaviors of all players competing in the European Under 19 and Under 17 Championships (2018). In this letter, I will provide you with information about the project and what implications this has for you.

Object
The object of the study is to investigate visual search behaviors of all players competing in the European Under 17/19 Championships in 2018. The goal of the study is to get a deeper understanding of what top youth players in different playing positions look at during matches and link this to performance. The study is part of my doctoral thesis at the Norwegian School of Sport Sciences.

Who is responsible?
The Norwegian School of Sport Sciences in collaboration with the German Football Federation conducts this study.

Why this orientation?
You receive this orientation because you are the team manager of a national team that are included in the study. Because of the difficulty reaching out to each individual player, I will request that you, if possible, could pass on this information to the players involved.

What does participation mean for you?
This study is solely a video analysis study. We only look at video taken from the matches. This includes both footage and sound. Names, date of birth and playing position will be included, but all names will be anonymous and protected behind a code key.

This study will not affect you or your players in any way.

Voluntary participation
The participation in the study is voluntary. If a player reports to me that he does not wish to participate, then I will not use his data in the study. This will not have any negative consequences for that participant.

Your personal protection-How information are stored
We will only us the information about your players as described in this letter. We treat the information with the highest level of confidentiality.

- *Only myself, my supervisor, and a few master students will work with the data.*
- *The names will be stored safely in a password protected external hard drive, with a code key linking them to the data.*

The participants cannot be identified directly, but can be identified indirectly based on the playing position and nationality of the player.

What happens with the information after the end of the project?

The project will finish in 31.12.2019 and data will be stored until 31.12.2030.

Kind Regards

Project leader
(Karl Marius Aksum)

Appendix C

Approval letter from NSD (Paper I)

Karl Marius Aksum
Postboks 4014 Ullevål stadion
0806 OSLO

Vår dato: 19.01.2018 Vår ref: 57718 / 2 / EPA Deres dato: Deres ref:

Vurdering fra NSD Personvernombudet for forskning § 31

Personvernombudet for forskning viser til meldeskjema mottatt 12.12.2017 for prosjektet:

57718	*Visual perception and action in professional football games: A tracking based 4Kvideo analysis of offensive and defensive visual exploratory behavior (VEB) and prospective control of action.*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Karl Marius Aksum*

Vurdering

Etter gjennomgang av opplysningene i meldeskjemaet og øvrig dokumentasjon finner vi at prosjektet er meldepliktig og at personopplysningene som blir samlet inn i dette prosjektet er regulert av personopplysningsloven § 31. På den neste siden er vår vurdering av prosjektopplegget slik det er meldt til oss. Du kan nå gå i gang med å behandle personopplysninger.

Vilkår for vår anbefaling

Vår anbefaling forutsetter at du gjennomfører prosjektet i tråd med:
- opplysningene gitt i meldeskjemaet og øvrig dokumentasjon
- vår prosjektvurdering, se side 2
- eventuell korrespondanse med oss

Vi forutsetter at du ikke innhenter sensitive personopplysninger.

Meld fra hvis du gjør vesentlige endringer i prosjektet

Dersom prosjektet endrer seg, kan det være nødvendig å sende inn endringsmelding. På våre nettsider finner du svar på hvilke endringer du må melde, samt endringsskjema.

Opplysninger om prosjektet blir lagt ut på våre nettsider og i Meldingsarkivet

Vi har lagt ut opplysninger om prosjektet på nettsidene våre. Alle våre institusjoner har også tilgang til egne prosjekter i Meldingsarkivet.

Vi tar kontakt om status for behandling av personopplysninger ved prosjektslutt

Ved prosjektslutt 15.06.2018 vil vi ta kontakt for å avklare status for behandlingen av personopplysninger.

Se våre nettsider eller ta kontakt dersom du har spørsmål. Vi ønsker lykke til med prosjektet!

Katrine Utaaker Segadal

Eva J. B. Payne

Kontaktperson: Eva J. B. Payne tlf: 55 58 27 97 / eva.payne@nsd.no

Vedlegg: Prosjektvurdering

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 57718

SAMARBEIDSSTUDIE

Dere har opplyst i meldeskjema at prosjektet er en internasjonal samarbeidsstudie, hvor Norges idrettshøgskole er behandlingsansvarlig for den norske delen av prosjektet. Personvernombudet forutsetter at ansvaret for behandlingen er avklart mellom institusjonene, og anbefaler at dere inngår en avtale som omfatter ansvarsfordeling, hvem som initierer prosjektet, bruk av data, behandling av personopplysninger og eventuelt eierskap.

INFORMASJON OG SAMTYKKE

Utvalget er fotballspillere i den engelske toppdivisjonen Premier League. Det er opplyst i meldeskjema at dere har hatt kontakt med Arsenal Football Club og at klubben har gitt tilgang til å filme alle deres hjemmekamper. Det vil ikke bli tatt direkte kontakt med utvalget. Personvernombudet legger til grunn at tilgang til og publisering av direkte personidentifiserende opplysninger er klarert med klubben før datainnsamlingen begynner.

Personvernombudet vurderer at prosjektet har liten personvernulempe for fotballspillerne. Vi vurderer at det er av allmenn interesse at prosjektet utføres og at personopplysninger kan behandles med hjemmel i personopplysningsloven § 8 d). Det vurderes som uforholdsmessig vanskelig å gi individuell informasjon til utvalget. Forskeren kan derfor fritas fra informasjonsplikt, jf. personopplysningsloven § 20 andre ledd bokstav b.

INFORMASJONSSIKKERHET

Personvernombudet forutsetter at dere behandler alle data i tråd med Norges idrettshøgskole sine retningslinjer for datahåndtering og informasjonssikkerhet. Vi legger til grunn at bruk av privat pc/mobil lagringsenhet/skylagring er i samsvar med institusjonens retningslinjer.

PROSJEKTSLUTT OG VIDERE LAGRING

Prosjektslutt er oppgitt til 15.06.2018. Det fremgår av meldeskjema at du vil lagre datamaterialet med personopplysninger frem til 25.01.2021 for oppfølgingsstudier/ny forskning og for undervisningsformål.

Vi minner om at ny bruk av data kan være meldepliktig til personvernombudet.

Appendix D

Approval letter from NSD (Paper II)

NSD

Norges idrettshøgskole
Att. Karl Marius Aksum
kmaksum@nih.no

Vår dato: 07.09.2018 Vår ref: 60888 AMS/LR Deres dato: Deres ref:

VURDERING AV BEHANDLING AV ALMINNELIGE PERSONOPPLYSNINGER I PROSJEKTET «VISUAL SEARCH ANALYSIS OF FOOTBALL PLAYERS COMPETING IN THE UNDER-17 AND UNDER-19 EUROPEAN CHAMPIONSHIPS"

NSD - Norsk senter for forskningsdata AS viser til meldeskjema innsendt 24.05.2018. Meldingen gjelder behandling av personopplysninger til forskningsformål.

Etter avtale med den behandlingsansvarlige, Norges idrettshøgskole, har NSD foretatt en vurdering av om den planlagte behandlingen er i samsvar med personvernlovgivningen.

Vi beklager at vurderingen har tatt lang tid. Dette skyldes forhold ved prosjektet som hadde behov for avklaring, samt overgang til nytt personvernregelverk.

Resultat av NSDs vurdering:

NSD vurderer at det vil bli behandlet alminnelige personopplysninger frem til 31.12.2030.

NSDs vurdering er at behandlingen vil være i samsvar med personvernlovgivningen, og at lovlig grunnlag for behandlingen er samtykke.

Vår vurdering forutsetter at prosjektansvarlig behandler personopplysninger i tråd med:

- opplysninger gitt i meldeskjema og øvrig dokumentasjon
- dialog med Norges idrettshøgskole, og vår vurdering (se under)
- Norges idrettshøgskole sine retningslinjer for datasikkerhet, herunder regler om hvilke tekniske hjelpemidler det er tillatt å bruke
- Norges idrettshøgskole sine retningslinjer for bruk av databehandler, felles behandlingsansvar med andre institusjoner, og/eller behandling av personopplysninger utenfor EU

Nærmere begrunnelse for NSDs vurdering:

1. Beskrivelse av den planlagte behandlingen av personopplysninger

Formålet med prosjektet er å kartlegge visuell søksatferd og etterfølgende prestasjon med ballen, av spillere fra alle lag som deltar i europamesterskapene for gutter født etter 01.01.01 (U17) og gutter født etter 01.01.99 (U19), sommeren 2018. Målet med studien er både å sammenligne søksatferd blant elitespillere i ulike aldre, men også for å lage et rammeverk for hva som kreves av søksfrekvens for å kunne prestere i europatoppen, i ulike aldre og i ulike posisjoner på banen.

Datamaterialet vil være filmopptak av kamper. Det vil ikke bli tatt direkte kontakt med utvalget. Tillatelse til filming kommer fra det europeiske fotballforbundet UEFA. I tillegg vil trenerne bli informert om forskningsprosjektet slik at informasjon kan videreformidles til spillerne. Datamaterialet vil ikke inneholde direkte personidentifiserbare opplysninger.

NSD finner at informasjonsskrivet mottatt 28.08.2018 vil gi trenerne god informasjon om hva behandlingen innebærer og om hvilke rettigheter spillerne har. Trenerne skal videreformidle denne informasjonen til spillerne på vegne av behandlingsansvarlig.

2. Personvernprinsipper

NSDs vurdering er at behandlingen følger personvernprinsippene, ved at personopplysninger;

- skal behandles på en lovlig, rettferdig og åpen måte med hensyn til den registrerte
- skal samles inn for spesifikke, uttrykkelig angitte og berettigede formål og der personopplysningene ikke viderebehandles på en måte som er uforenelig med formålet.
- vil være adekvate, relevante og begrenset til det som er nødvendig for formålet de behandles for.
- skal lagres på en slik måte at det ikke er mulig å identifisere de registrerte lengre enn det som er nødvendig for formålet.

3. Lovlig grunnlag for å behandle personopplysninger

Det lovlige grunnlaget er allmenn interesse (art.6.1e jf personopplysningsloven § 8)

NSD vurderer at den planlagte behandlingen gjennomføres på en måte som ivaretar de registrertes rettigheter, jf. personvernforordningen art. 11-21. Dette ivaretas ved at behandlingsansvarlig informerer om forskningsprosjektet gjennom landslagene.

4. De registrertes rettigheter

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har Norges idrettshøgskole plikt til å svare innen en måned. Vi forutsetter at prosjektansvarlig informerer institusjonen så fort som mulig og at Norges idrettshøgskole, har rutiner for hvordan henvendelser fra registrerte skal følges opp.

5. Informasjonssikkerhet

NSD forutsetter at personopplysningene behandles i tråd med personvernforordningens krav og institusjonens retningslinjer for informasjonssikkerhet.

6. Varighet

Ifølge meldeskjema skal personopplysninger behandles frem til 31.12.2030. Opplysninger som kan knyttes til en enkeltperson skal da slettes/anonymiseres.

Norges idrettshøgskole må kunne dokumentere at datamaterialet er anonymisert.

Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan bli identifisert.

Meld fra om endringer

Dersom behandlingen av personopplysninger endrer seg, kan det være nødvending å melde dette til NSD via Min side. På våre nettsider informerer vi om hvilke endringer som må meldes. Vent på svar før endringen gjennomføres.

Informasjon om behandlingen publiseres på Min side, Meldingsarkivet og nettsider
Alle relevante saksopplysninger og dokumenter er tilgjengelig:

- via Min side for forskere, veiledere og studenter
- via Meldingsarkivet for ansatte med internkontrolloppgaver ved Norges idrettshøgskole

NSD tar kontakt om status for behandling av personopplysninger
Etter avtale med Norges idrettshøgskole vil NSD følge opp behandlingen av personopplysninger underveis og ved planlagt avslutning.

Vi sender da en skriftlig henvendelse til prosjektansvarlig og ber om skriftlig svar på status for behandling av personopplysninger.

Se våre nettsider eller ta kontakt ved spørsmål. Vi ønsker lykke til med prosjektet.

Med vennlig hilsen

Marianne Høgetveit Myhren
seksjonsleder

Anne-Mette Somby
spesialrådgiver

Appendix E

Approval letter from NSD (Paper III and IV)

Karl Marius Aksum
Seksjon for coaching og psykologi Norges idrettshøgskole
Postboks 4014 Ullevål Stadion
0806 OSLO

Vår dato: 30.03.2017 Vår ref: 52593 / 3 / LB Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 01.02.2017. Meldingen gjelder prosjektet:

52593	*Visual exploratory behaviour in 11 vs 11 football match play: A Tobii eye tracker analysis of positional requirements*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Karl Marius Aksum*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvernombud/meld_prosjekt/meld_endringer.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.12.2018, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Lene Christine M. Brandt

Kontaktperson: Lene Christine M. Brandt tlf: 55 58 89 26
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 52593

Utvalget informeres skriftlig og muntlig om prosjektet og samtykker til deltakelse. Informasjonsskrivet er godt utformet, såfremt følgende tilføyes/endres, jf. telefonsamtale med prosjektleder 29.03.2017:

- Det legges til en setning under avsnittet "Hva innebærer deltakelse i studien?" om at det også vil samles inn noe fotballstatistikk om spillerne som deltar i prosjektet. - Dato for prosjektslutt justeres til 31.12.2018.
- Setningene "Alle persondata vil da bli slettet, og videofiler vil bli lagret på en intern datamaskin på Norges Idrettshøgskole. Kun jeg og veileder vil ha tilgang til disse filene i ettertid" omskrives. Vi anbefaler følgende formulering: "Alle innsamlede data anonymiseres, og videoopptak slettes, senest ved prosjektslutt".

Data samles inn ved at en treningskamp mellom to fotballag filmes. Det vil også tas videoopptak via videobriller som spiller har på seg. Samtlige spillere på banen vil således være en del av videoopptakene. Personvernombudet ønsker å understreke at deltakelse i forskning er frivillig, og at det derfor må legges til rette for at det kun registreres personopplysninger om spillere som har samtykket til å delta. Prosjektleder opplyser per telefon at de vil vurdere hvordan det kan legges opp slik at det er et alternativt treningsopplegg for de som evt. ikke ønsker å delta.

Dersom det er tilskuere tilstede under kampen, og disse kan bli en del av videomaterialet, vil prosjektleder informere tilskuerne om prosjektet. Ombudet legger til grunn at tilsvarende informasjon som gis i informasjonsskrivet til spillerne, gis eventuelle tilskuere muntlig eller ved at det henges opp skriv i kamplokalene. Filmingen vil også foregå fullt synlig.

Data samles også inn ved at det registreres noe fotballstatistikk om spillerne som deltar i prosjektet.

Det tas høyde for at det vil kunne fremkomme sensitive opplysninger (om helseforhold, jf. personopplysningsloven § 2 nr. 8 c)) på videoopptakene, dersom spillere blir skadet under kampen.

Personvernombudet legger til grunn at forsker etterfølger Norges idrettshøgskole sine interne rutiner for datasikkerhet. Dersom personopplysninger skal lagres på privat pc, bør opplysningene krypteres tilstrekkelig.

Forventet prosjektslutt er 31.12.2018, jf. telefonsamtale. Ifølge prosjektmeldingen skal innsamlede opplysninger da anonymiseres.
Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan gjenkjennes. Det gjøres ved å:
- slette direkte personopplysninger (som navn/koblingsnøkkel)
- slette/omskrive indirekte personopplysninger (identifiserende sammenstilling av bakgrunnsopplysninger som f.eks. bosted/arbeidssted, alder og kjønn)
- slette videoopptak

Karl Marius Aksum // Visual Perception in Elite Football