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Visual exploratory activity and virtual reality in soccer: challenges and research gaps

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Virtual reality (VR) provides a simulated environment where soccer players can actively engage in lifelike scenarios potentially enhancing their performance (e.g., tactical awareness). The integration of VR technology into training has grown significant in recent years, driven by its immersive and versatile nature. Practitioners often claim that VR improves players' perception skills, such as visual exploratory activity (VEA). VEA is 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. It was studied to be an indicator for elite players and successful performance, especially for passing. However, the current literature presents limited studies on this topic. Therefore, this brief report explored, via a narrative review, several potential ways in which VR could be examined to determine its effectiveness in enhancing VEA in soccer players and, consequently, their performance (e.g., passing).

KEY WORDS: Artificial Intelligence, Affordances, Decision making, virtual reality, visual exploratory activity, scanning.

Introduction

In recent years, the use of virtual reality (VR) technology in professional soccer has grown significantly. This surge in popularity may be attributed to the increasing commercial availability of VR applications, which are emerging as a promising tool for education and training purposes (Cotterill, 2018; Thatcher et al., 2021). VR provides an immersive experience, allowing users (e.g., players) to participate in lifelike scenarios as well as to receive real-time feedback (Gray, 2017). It immerses users in a manufactured synthetic environment, designed to transcend the restrictions of the real world. This experience is facilitated through a computer-generated entirely in an artificial

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digital setting, where users engage with their surroundings by utilizing a variety of devices such as motion controllers (Alnagrat et al., 2014; Chan et al., 2022).

Practitioners advocate for the multifaceted applications of VR including rehabilitation, performance analysis (e.g., tactical analysis), and the development of perception abilities such as vision exploration. For instance, VR was studied as a rehabilitation tool to maintain mental training, using soccer-specific drills with a virtual ball and avoiding physical contacts (Schultheis & Rizzo, 2001). Similarly, Shimi et al. (2021) investigated the role of attentional skills in executing a goalkeeping task in VR. Their study found that VR simulations can help goalkeepers develop several mental skills, particularly attentional abilities such as alerting and orienting. Moreover, in situations where players have limited mobility, such as post-surgery, VR allows them to review footage of their previous matches from their own perspective or alternative ones (e.g., the goalkeeper's prospective), helping to maintain cognitive engagement (Greenhough et al., 2021). Lastly, Fortes et al. (2021) found that VR leads to greater improvements in decision-making and visual search behavior in young soccer players compared to video screens.

Experienced coaches and players emphasized the usefulness of VR. Renowned coaches, such as Arsène Wenger and Vincent Kompany[1], underlined its potential for (re)experiencing matches, understanding decision-making processes, and cutting-edge cognitive development (*Arsène Wenger*, 2024; Gaughan, 2018). Furthermore, some elite players who have trained with VR programs have also endorsed its application for enhancing vision skills, such as visual exploratory activity (VEA - known also as "scanning"), particularly during injury recovery periods (Arsène Wenger, 2024). Accordingly, several VR companies are promoting their products claiming to improve players' VEA (SkySports, 2024). VEA is recognized as an essential perceptual skill for elite players by sport psychology scholars (Helsen & Starkes, 1999; Wirth et al., 2021). However, there is limited literature on the effects of VR on performing VEA and possible effects on the players' performance (e.g., their successful passes).

Therefore, this brief report aims to examine previous VEA studies and the impact of VR on psychological skills in soccer players through a narrative review, ultimately presenting research questions for further investigation. The structure of paper is as follows: first, it explores the importance of VEA in soccer performance by reviewing the current literature. Next, it examines

[1]Notably, according to several sources on internet, Vincent Kompany is also an investor in the VR company Rezzil.

existing studies on VEA and VR. Finally, it identifies research gaps and discusses potential applications.

Visual Exploration Activity in Soccer

VEA was defined by Jordet (2005) as "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, and other environmental objects or events, relevant to the carrying out of a subsequent action with the ball"(p. 143). VEA provides an early perception of potential actions (i.e., affordances) within the situation. This ability to quickly assess and act on relevant information is closely tied to a player's perceptual skills, which allow them to make effective decisions and anticipate future actions based on available affordances (e.g., teammates' positions and opponents' movements) (Caso et al., 2023; Jordet et al., 2020). In addition, VEA has been consistently linked to a higher likelihood of successful passing outcomes following ball reception (Aksum et al., 2021a, 2021b; Caso et al., 2023; Eldridge et al., 2013; Jordet et al., 2020; McGuckian et al., 2017, 2018, 2020; Phatak & Gruber, 2019; Pokolm et al., 2022). Moreover, elite football players exhibit higher levels of VEA, performing it more frequently before receiving the ball than less skilled players (Aksum et al., 2021b; Jordet et al., 2020; McGuckian et al., 2020; Pokolm et al., 2022). This early and increased use of VEA highlights the the essential role of perceptual skill in soccer (Savelsbergh et al., 2006; Williams et al., 1994). Finally, recent research showed that players who actively explore their surroundings during the penultimate pass (i.e., the pass made before the final pass that a player receives) are more likely to achieve higher passing success rates (Caso et al., 2023). This suggests that the timing of VEA, particularly before receiving the ball, serves as an anticipation factor, enabling players to identify early possibilities for action in a given situation.

From the ecological psychology approach, VEA is a search for information involving the entire body (Gibson, 1966, 1977). This process results in attunement to information specifying the most relevant possibilities for action. Consequently, perceptual skills in soccer are conceptualized as flexible, largely unreflective, situated awareness, rather than the accumulation of shared conscious knowledge. Essentially, skill emerges from continuous, active visual exploration of the environment, allowing players to adapt flexibly to emerging and dissolving possibilities for action during a match (Fajen et al., 2008). Accordingly, VR provides an unique way to replicate soccer environments and potentially enhance VEA (Neumann et al., 2018; Wirth et al., 2021). Thus, in the context of sport psychology and training methodologies, the integration of VR becomes a promising tool for enhancing players' VEA and performance such as passing.

Virtual Reality and Visual Exploratory Activity

Research highlighted the bidirectional link between action and perception in sports, emphasizing the need for the continuous interplay between informational constraints and movements (Davids et al., 2013). This relationship extends to the transferability of perceptual motor skills from the virtual to the real-world settings, demonstrating the effectiveness of VR as an (additional) training tool (Gerwann et al., 2025; Gray, 2017; Michalski et al., 2019; Tirp et al., 2015). For example, Gray (2017) studied the transfer of perceptual motor skills from VR to real-world performance in baseball batting. The study demonstrated that adaptive virtual training significantly improved 'real-world' batting skills, highlighting the potential for VR to enhance sport performance through the effective transfer of perceptual and motor abilities. Similarly, a study by Michalski et al. (2019) explored how VR training could improve basketball shooting accuracy, with results indicating that virtual training could lead to significant improvements in shooting performance in real-world scenarios. Meanwhile, Tirp et al. (2015) explored the effectiveness of VR training in improving perceptual and motor performance in dart throwing. Their study found that both virtual and real training conditions led to improvements in quiet-eye[2] duration.

These findings highlight VR as an effective tool for training and skill development across various sports by bridging the gap between virtual and real-world performance. However, soccer is a sport in which players are likely to exhibit greater variability of actions (and consequently motor skills, see Caso & van der Kamp, 2020) compared to baseball and darts. Nevertheless, to a certain degree, it could be presumed that by immersing players in artificial soccer scenarios, VR can create interactive experiences that simulate real-world actions. Accordingly, promising findings suggest that VR can accurately assess head motion characteristics related to VEA (Wirth et al., 2021). Similarly, Causer et al. (2011) found that VR training positively impacted the

[2] Quiet-eye duration is the final steady gaze on a target before executing a movement, crucial for accuracy in sports. Longer duration is often linked to better performance.

anticipation skills of cricket players. Moreover, Neumann et al. (2018) noted that using full-body kinesics natural mapping controllers in a virtual environment enhances immersion compared to traditional input devices, potentially improving VEA skills. Therefore, VR provides an opportunity for the players to practice and refine VEA skills, particularly beneficial for injury recovery. However, to the best of the available knowledge, only a limited number of studies that have directly investigated the relationship between VR and VEA (as well as performance) in soccer. In particular, no studies have examined the relationship between VR, VEA, and successful passing.

Research gaps

The promising outcomes from several studies lay the foundation for understanding VR's impact on VEA in soccer players (Causer et al., 2011; Wirth et al., 2021). However, these findings require experimental verification and further exploration of VR's representativeness and the transferability of motor skills in simulating real-world scenarios for effective VEA education and training. Accordingly, Wirth et al. (2021) highlighted the need for a direct comparison between VR and on-pitch VEA performance to determine the most accurate representation of reality. Specifically, they recommended incorporating multimodal stressors inside the virtual environment, such as the crowd sounds (see Zheng et al., 2023) and other environmental factors that could impact VEA. Moreover, practitioners expressed enthusiasm for VR's potential in enhancing decision-making processes (Arsène Wenger, 2024; Gaughan, 2018). This provides extra motivation for future studies to investigate VR's specific role in improving VEA, potentially leading to the development of innovative (additional) educational and training programs. For instance, numerous elite soccer clubs divide their training sessions into team exercises and skill-focused drills. Consequently, VR may be integrated into these training sessions. Hence, this brief report advocates for the need to research how VR impacts VEA in soccer players' performance, potentially starting with successful passing, given the numerous studies that have found a positive correlation between VEA and successful passing (Aksum et al., 2021a, 2021b; Caso et al., 2023; Eldridge et al., 2013; Jordet et al., 2020; McGuckian et al., 2017, 2018, 2020; Phatak & Gruber, 2019; Pokolm et al., 2022).

However, first all, the level of validity and fidelity of VR should be examined to be at a similar level of the real-settings (i.e., the match), especially the psychological fidelity (Gray, 2019; Stoffregen et al., 2003). Validity relates to detailed measurement and the reproduction of real task performance (Stoffregen et al., 2003), whereas fidelity refers to how well a simulation reconstructs real-world environments, both in terms of appearance but also the emotional states, cognitions and behaviors that elicits from its users. Fidelity can be examined across different levels, including the physical, psychological, construct, emotional/affective and, ergonomic and biomechanical fidelity (Harris et al., 2021; Ijsselsteijn et al., 2004). Fidelity can be verified by using integrated and non-integrated tools. For example, eye tracking and inertial measurement units (IMU) could be used to examine whether the eye and head movements are as those which the players actually perform during real matches. Yet, these tools may be also used to improve performance. For instance, it might be possible that players would not be educated enough in their visual orientation and head movements (e.g., the timing). Thus, the eye tracking and head movements may be compared between real footages with the footages from VR scenarios and guide the players' to improve their awareness via VR. Further, limitations such as peripheral vision restrictions with head-mounted displays and the absence of physical feedback may impact the full sensory experience of real-world soccer and it needs further research (Haar et al., 2021). Whereas, to test the validity level, several methods may be used such as the use of surveys, interviews and behavioral observations (i.e., via video-notational analysis) (Caso et al., 2025; Howie & Gilardi, 2021; Kamińska et al., 2019). Hence, this paper briefly explores these considerations and raises also questions about the validity and fidelity of VR as an educational and training tool.

Once the fidelity and validity level are examined, exploring the integration of VR into the training programs and evaluating their effectiveness in enhancing VEA and potentially related performance enhancements, are important areas for further investigation (Rojas Ferrer et al., 2020; Wirth et al., 2021). For instance, Lozano-Tarazona and Pinzon (2023) studied whether the header motor skill in soccer can be transferred from VR training to real-settings. Hence, future studies may examine the VEA training of two players with similar positions and tactical movements, such as two midfielders or two central defenders in a 4-4-2 formation shape (see Caso et al., 2024). The VR training could be designed using recreated scenarios which the players encounter during matches. The match tracking data may derived from their matches played. However, players could be also trained using the match tracking data from teams who play with a higher tempo. For example, youth players could be trained in matches played by adult elite teams. Therefore, future studies may also explore the impact on the VEA performance of players who are trained in higher match tempos. If positive effects are found, further research could determine the optimal tempo and number of sessions needed for maximum benefit.

However, VR training should be initially studied without variations in match tempos. The VR training (and research) could consist of systematically training one of the two players selected with the same tactical position (e.g., two central defenders) and the same amount of (team)training, for certain several periods (e.g., twice a week). For example, player A would extra train in VR either before or after the team trainings or on separate days. While, player B has only team training (where player A was trained). To examine the VEA frequency and performance differences during matches, video-notational analysis stands as an ecologically valid method (Araujo et al., 2009). Therefore, the players' VEA and their relationship with performance could be monitored during trainings and matches via video-notational analysis. The frequency of VEA and the performance metrics could be monitored and studied over specific time intervals to scientifically validate the improvements in players undergoing VR training. Artificial intelligence (AI) automatic analysis may facilitate this process (Hughes & Franks, 2004). Analysts, instead of examining VEA via video-notational analysis, they could rely on AI (video)analysis, i.e., the automatic video analysis on both the VEA frequency and performance. Furthermore, AI may aid the creation of scenarios for personalized trainings. For example, several clubs play in diamond shapes movements, where players strategically position themselves to form triangles on the field (see Caso et al., 2023). Hence, AI could generate such scenarios, and possibly an AI coach may analyze these movement patterns and provide real-time feedback.

In the rehabilitation context, VR provides a means to train mental components using soccer-specific drills with a virtual ball, eliminating physical contact (Greenhough et al., 2021). Jordet (2005) found that via an imagery intervention program, VEA was improved in three elite soccer players. Thus, future studies could investigate on whether VR trainings for injured players improves their VEA performance once they return to team trainings and matches. Finally, in a study on youth elite players, Pokolm et al. (2022) found that those players who played more national team matches exhibited a higher VEA frequency. Similarly, Aksum et al. (2021b) observed that during the finals of the UEFA European Championship, U19 players performed more scans compared to their U17 counterparts. These findings suggest that VEA could be a reliable indicator for talent identification. In soccer clubs, especially in the youth teams, it is common that external players undergo trial periods before recruitment. Therefore, clubs could use VR, potentially integrated with eye tracking technology, to analyze VEA frequency and possibly comparing it with peers of the same age.

In conclusion, by addressing these queries, future researchers could contribute to a more nuanced understanding of the relationship between VR, VEA (and possibly performance), ultimately shaping the future of soccer training and education, rehabilitation, tactics and talent scouting. However, it is important to examine the level of validity and fidelity of VR in the virtual soccer environments. Lastly, the integration of AI has the potential to facilitate for automatic analysis and to transform how VR systems interact with players, adapting simulations dynamically based on individual learning patterns and skill progression.

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