

READ-THE-GAME skill assessment with a full  
body immersive VR soccer simulation

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*Dedicated to my loving family;  
to those who taught me how to walk, and to those who will walk with me from now on.*



## ABSTRACT

In this work, we present a virtual reality (VR) system to assess soccer players' ability to read-the-game. Read-the-game refers to the visual exploratory behavioral patterns and related cognitive elements necessary to make accurate in-game decisions. Our multidisciplinary approach spans the Sports Science domain, focusing on the skill development's visuomotor component in a VR simulation, considering VR as a powerful perception-action coupling training option for immersive visual training. Also, we analyze the psychological aspect related to the exerted sense of presence. In the human-computer interaction (HCI) domain, we consider the setup for achieving an immersive environment with full-body interaction. The system records the user's head excursions, showing the visual exploratory activity (VEA) during a soccer match simulation, showing each player's behavior, making passing decisions under pressure from rivals. The elicited sense of presence is measured with the Igroup Presence Questionnaire (IPQ) applied to players of different experience levels. In the HCI domain, integrating head and body motions was compared with button press inputs for passing the ball, exploring the input effect in the elicited sense of presence. We observe a statistically significant difference in the VEA performance between players of different levels of experience.

Additionally, we introduce the possibility of using the athletes' brain activity patterns to assess their attention level in a VR environment by implementing novel EEG headset technology. Finally, we showcase an alternative application of the presented method for measuring VEA. This example serves as a showcase of the potential of our approach for measuring human VEA within a self-contained VR simulation in various fields.

Keywords: Virtual Reality, Sports, Sensory Perception, Vision.





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# CHAPTER 1

## INTRODUCTION

### 1.1 Motivation

This thesis aims to address a significant necessity for validated technological solutions for assessing and training soccer players' decision-making abilities. Specifically, the main focus is on measuring the athletes' visual excursion patterns in a controlled, immersive Virtual Reality (VR) environment.

In association sports football, most commonly known as football or soccer, coaches share a simple yet difficult question that remains unanswered: Where do soccer players look at before making in-game passing decisions? Or, in other words, how do they Read-the-Game? The inspiration for this work comes from the necessity to address such needs.

During a soccer game, players are required to proactively engage in visual exploration to gather essential information for accurate in-game decisions. In general, coaches agree on the necessity of a substantial visual scanning from the players before making informed play decisions, like towards which teammate they should pass the ball [1]. Therefore, it is relatively common to hear coaches during training sessions demand more visual exploratory engagement from their players. While every coach tends to develop their methodology and training approach, there are standard practices and terminologies shared amongst top coaches to communicate and request certain behaviors from their players. In particular, there is one term widely used that inspired this research project endeavor: "Read-the-Game."

Read-the-Game's concept has been employed as an umbrella term that encompasses the visual perception-cognitive skills needed by players to act and react effectively to unfolding events during a competitive match [2]. A previous study survey revealed that professional English coaches consider players of certain positions have a better ability to Read-the-Game. In particular, center back and center midfielders were identified as more proficient [3]. However, no concrete, measurable parameters are provided as the baseline with which the ability to Read-the-Game is measured, only a reference to their overall subjective evaluation. In other words, coaches agree and share a conceptual idea of the ability to Read-the-Game, and subjectively evaluate each player according to their interpretation of the concept. As an anecdote, in his youth, the author himself suffered the confusion of not knowing what the coach meant when he asked him to better Read-the-Game during his high school team practice session. This lack of concreteness may lead to misuse of the term and even bad coaching practices that may hinder young players' development.

## **1.2 Overview**

This work aims to help define the elements related to the complex concept of Read-the-Game as an operational definition, structured as a measurable skill with objective parameters relevant to the term's critical conceptual elements. The present thesis identifies one of the less explored primary visual critical elements of the skill. This work also wants to serve as the starting point for future researchers interested in advancing the study and development of the Read-the-Game skill from an engineering approach. With that in mind, we propose and implement a VR-based technological solution for measuring one of the Read-the-Game foundational elements. In particular, the Visual Exploratory Activity (hereafter referred to as VEA) of the players was identified as the critical perceptual element to measure and study as the starting point for developing the Read-the-Game skill. This work further identifies the VEA

behavior's sub-elements, proposing the user's head rotation as an essential parameter to assess and develop the players' ability to effectively scan their surroundings.

We believe this work opens a new vista for the Human-Computer Interaction (HCI) research community by providing insights into how full-body immersive VR can benefit soccer-specific coaching applications. We explore how the proposed VR system design choices may or may not affect the players' VEA performance concerning the immersion provided. A high level of immersion of a VR system can be assessed by its psychological byproduct, known as Presence perceived by the user [4]. Precisely, the elicited sense of Presence of the system is measured and compared while utilizing two different controller input options for interacting with the Virtual Environment, hereafter referred to as VE. A comparative statistical analysis is performed, searching for a possible relationship between the input options, their respective elicited Presence, and the VEA performance.

### **1.3 Research Question**

In highly dynamic sports like soccer, the player's situation continually changes, which demands constant visual exploration of the surroundings, leading to informed game decisions. The consensus is that more experienced players are more effective in gathering visual information than less experienced ones [5]. This topic attracts much attention from the research community and sports specialists searching for better methods to measure and train the players' visual perception performance. However, most of the existing literature focuses on studying the total number of eye fixations, duration, and location under controlled conditions, with conventional video recordings of previous matches presented to the players as stimuli [6]. In contrast, this thesis aims to measure the visual exploratory patterns with a different approach, providing a fully immersive three-dimensional representation of a soccer match as visual stimuli. Thus, the system design choice of utilizing VR technology is vital for enabling the

utilization of the complete Field Of Regard (FOR) of the player for possible visual explorations. The proposed approach provides new insights for elucidating where players look under highly stressful in-game situations.

Based on the premise introduced above, the foundational question defined for this work is: **Can we assess the player's Visual Exploratory Activity (VEA) performance with full-body immersive VR?**

While VR technology has been widely explored for sports training and assessment in team ball sports [7], the existing solutions still present various flaws and shortcomings, mainly due to poor system design choices and deficient experimental designs. Hence, a proper evaluation of the proposed VR system as a robust solution for Read-the-Game skill development was deemed necessary. Visional coverage of soccer players should be discussed in a combination of eye, head, and body rotation in a specific real game situation. Accordingly, we test the system's capacity to accurately measure soccer players' VEA activity while providing a high sense of immersion. By focusing on the elicited sense of Presence, which is the psychological byproduct of the provided sense of immersion, we assessed the proposed system's effectiveness as a proper training and assessment solution for VEA performance.

## **1.4 Contribution**

The contribution of this work lies in the intersection of Sports Science, Psychology, and HCI domains. To the best of the author's knowledge, this is the first work to propose an operational definition for the Read-the-Game skill, clarifying the specific sub-elements of the term regarding the visual perception required for better in-game decision making.

Based on the Read-the-Game skill's defined elements, we provide a concrete method to assess the player's Visual Exploratory Activity (VEA) performance with full-body immersive VR. While research works already explored soccer players' visual behavior substantially by

focusing only on their visual fixations, there is a surprising lack of works dedicated to the players' head rotation.

Hence, this thesis presents a novel approach for assessing one of the critical visual sub-elements by using HMD's in a VR simulation, focusing on the players' head excursion as the starting point for elucidating their VEA performance. We provide a performance assessment technological solution in a sport, regularly asking for them, given both its popularity and competitiveness. Furthermore, we demonstrate how full-body immersive VR is beneficial to VEA performance inside the VE. For doing so, we compare the level of Presence perceived by the players in VR while utilizing two different input methods for passing the ball to a teammate under real-life like time constraints. Then, by correlating the level of Presence with the VEA performance achieved with different input options, we found that Kinect offered a better experience. Thus, this dissertation provides new insights into the relationship between full-body interaction and task-specific performance within a VR soccer simulation.

Finally, the system is designed with portability and accessibility in mind. The selected components are commercially available and relatively accessible in price. As a result, the proposed system serves as a testbed for future training solutions, easy to deploy by practitioners and researchers alike.

## **1.5 Thesis Structure**

The following chapters of this doctoral dissertation are composed as follows:

In Chapter 2, the related works that motivated this dissertation will be introduced, clarifying the necessity of technological solutions like the one provided by this work from a sports science perspective. In contrast to sports practitioners' ideal state, the current situation will be presented, clarifying the proposed approach's need.

In Chapter 3, the need and operational definition of the Read-the-Game skill will be discussed, based on existing literature and practitioners' usage of the terminology. The sub-elements that comprise the Read-the-Game skill will be clarified, showing the necessity of further studying the player's VEA concerning their head excursions. Also, the importance of full-body interaction for creating immersive sport VR simulations is discussed. The chapter concludes by explaining the method and criteria for defining players' VEA performance with their head rotation obtained with an HMD.

Chapter 4 explains why VR technology was chosen as the medium for studying sport-related visual performance. The VR elements that need to be considered to measure the Read-the-Game skill in a Virtual Environment (VE) are identified. The VE construction will be explained, considering the necessary elements for achieving the desired level of immersion. The chapter then focuses on the psychological byproduct of VR Immersion, known as the sense of Presence, explaining how it is measured and evaluated with psychometric questionnaires. The chapter ends by explaining the method to achieve full-body interaction.

For Chapter 5, the experiments done to assess VEA performance between beginner and amateur players are presented. The results are introduced and analyzed statistically.

Chapter 6 discusses the results obtained in chapter 5 and mentions the potential implications of these findings in sports science, psychology, and HCI fields. Furthermore, the

chapter introduces the latest advancements of our work and the associated new prototype system, which considers other elements relevant to the Read-the-Game skill as defined in chapter 3. The chapter ends by introducing an alternative application of the proposed method in a side project. This shows the potential of the technological achievement of our work in fields outside of the sports sciences.

Finally, in Chapter 7, the present work's conclusion is presented, followed by the bibliography and the list of publications on which this thesis was based.



## **CHAPTER 2**

### **RELATED WORKS**

A significant portion of the existing academic works concerning soccer skills assessment and development is focused on skill identification in small-sided and conditioned games. Researchers and practitioners tend to concentrate on skill-related performance at the championship level, the effect of training conditions, level and position-specific training protocols, talent development, and identification, amongst others [8]. All these research efforts share the common goal of elucidating what is required to achieve the best game outcomes by soccer players in the end.

However, identifying the necessary elements required by players for achieving the best outcomes is a rather complicated task. The main reason is that soccer is a complex and demanding sport that includes physical, psychological, technical, and tactical components that are highly demanding and are all relevant to performance [9] [10] [11] [12] [13]. The expert's consensus is that for the best game outcome in a dynamic team sport like soccer, which changes rapidly and continuously during a match, each player's situational awareness can be the key between winning or losing a game. Therefore, plenty of attention has been dedicated to identifying the specific perceptual-cognitive skill elements utilized by top athletes to guide their actions, such as decision making, anticipation, and pattern recall [6] [13] [14].

Among the perceptual-cognitive studies, vision is widely considered one of the critical elements of good performance indicators in sports since it is the primary tool with which athletes perceive their surroundings. Naturally, new technological methods that focus on the study and development of sport-specific visual and cognitive abilities are constantly emerging [15].

When it comes to soccer-specific solutions, most of the existing research has been focused on eye movement, ignoring the significant relationship between eyes, head, neck, and body rotation to explore the 360° degrees of the player surroundings [16] [17]. Human eyes are limited in the area of coverage, with the maximum horizontal field of view covering approximately 190° degrees with both eyes, with about 120° covered by binocular vision [18]. It has been stated that the highest resolution of the human eye applies only to the central area of about 2° in diameter of vision with high foveal cognitive load, and 4° at most with a low level of foveal load [19] [20]. In other words, the area where our eyes can see information meaningfully and in full detail is quite narrow. Considering that soccer presents a relatively high cognitive load due to its inherent dynamism, the need to optimize the visual exploratory patterns in wide angles to achieve significantly more extensive coverage becomes clear.

Visional coverage of soccer players should be discussed as the combination of eye, head, and body rotation in a specific game situation. Unfortunately, many research works set some limitations on their investigation. As stated in a recent extensive literature review, including thirty-eight studies, "much of the visual perception research in sport has focussed on the movements of the eyes" [6], ignoring the head and body rotational behavior. Furthermore, the limited existing work that does attempt to show a solution focusing on the head excursion has specific shortcomings, such as not utilizing the whole Field of Regard (FOR) of the player as a valid playing option [21]. Therefore, we should further investigate the soccer player's visual scanning patterns, focusing on head rotational behavior to accurately represent VEA performance.

From the manager's subjective perspective, the required attributes for obtaining the best outcomes depending on the player's position vary, including the ability to make decisions, emotional control, and the ability to Read-the-Game [22]. The latter term has been suggested

to be the conglomerate of required visuoperceptual exploratory abilities to make the most accurate in-game decisions and react to unfolding events [2]. However, even if managers agree on the importance of the skill and have a rough idea of its relationship with visual dynamics, the proper operational definition that makes possible a unified evaluation of the skill is missing.

A sensitive lack of effective collaboration between sport science researchers and practitioners have been suggested previously in relevant literature [12] [23]. In this regard, the main reason for this disassociation between the scientific community and the sport's practitioners is highly related to the fact that scientists tend to focus on problems specific to their area of interest. Therefore, researchers are inclined to formulate questions that are not in line with realistic environments and situations. In other words, researchers tend to overlook the inherent complexities of the game by formulating their research questions to solve problems specific to their disciplines rather than the coaching requirements [12] [24]. Instead, by focusing on the Read-the-Game skill in this work, we formulate our research question starting from the coaches' perspective, utilizing terminology not only familiar to them but identified as a crucial concept to train and develop in their daily routine [22]. To effectively address the sports practitioners' need, it was necessary to identify the objective parameters that define the Read-the-Game skill in the function of the cognitive and visual elements, measurable with objective criteria.

Seminal research that employed video-based simulations projected in a conventional screen coupled with standard visual function tests suggested that while some perceptual skills are developed early by young players, the essential ability to accurately Read-the-Game in sport is developed later in a player's career [25]. However, in the same study, some findings point to a clear differentiation between elite and sub-elite players within the same age group, with the former continually outperforming the latter. The researchers attribute this difference to the

capacity of elite players to "effectively utilize and integrate contextual information with expectations stored in memory in ways that differ systematically from those of their sub-elite counterparts" [25]. While these findings are promising, the players' VEA was not assessed during real-life gameplay. To further assess these findings, it is required to perform tests comparing players' visual exploratory activity within the same age group and different expertise levels in a real soccer match context.

Previous work suggested that the skill to accurately "Read-the-Game is developed through sport-specific adaptations to perceptual-cognitive skills that include recognizing and recalling patterns of play, anticipating an opponents' actions, and showing greater situational awareness" [1]. Moreover, amongst the specific perceptual-cognitive abilities needed to accomplish top performance, VEA was found to be a reliable factor in measuring the player's perceptual skills, with a positive correlation between VEA frequency and ball performance [1] [26].

Based on the above, we propose and implement a full-body immersive VR soccer simulation that promotes the expression of the required perceptual skills during the game scene, including situational awareness, the anticipation of opponents' actions, and play-related pattern recognition while focusing on the VEA performance.

From a technological perspective, elite coaching staff acknowledges the importance of utilizing technology for enhancing their training practices. More specifically, regarding VR-based performance assessment solutions, there are overwhelming positive opinions concerning its untapped potential as a training solution. When asked about their subjective impressions regarding the technology potential, English Premier League coaching staff expressed opinions such as "I think VR can be very powerful, especially when other teams are not using it" [27]. However, there are unaddressed limitations in existing VR training proposals, such as

excessively prolonged periods of demanding cognitive activity, overwhelming physical engagement, and unproven task-specific elements (i.e., untested interactive modalities and exerted sense of immersion). Therefore, in our work, we design, test, and validate a technological alternative that serves as a solid bridge connecting the "probable" with the "possible." In a nutshell, we offer a bridge between the scientific and coaching worlds, aiming to establish an interdisciplinary technological and methodological foundational stone upon which the scientific community can further raise awareness regarding VR training's latent potential amongst the coaching professionals.

The in-depth technological details for achieving the aforementioned goals will be further introduced in the following chapters.

## **CHAPTER 3**

### **READ-THE-GAME SKILL IN FOOTBALL SOCCER**

#### **3.1 Need of the READ-THE-GAME skill**

First, soccer practitioners have to define and assess the player's development concerning their perceptual-cognitive behavior. In this regard, the present work further defines the umbrella term Read-the-Game, used widely by the soccer community but not defined operatively. The term was chosen not only for its wide adoption but also for the relevant perceptual-cognitive skills specific to soccer performance. By identifying the visual sub-elements that comprise the Read-the-Game concept, this work presents a clear differentiation in the critical areas that need to be addressed to improve player's situational awareness, anticipation, and overall in-game decision making.

Second, concerning technological solutions specific to soccer training and assessment, there is a substantial void that needs to be filled. That is the lack of effective options for VEA's correct assessment and training by focusing on the player's head excursion for optimum area coverage. In this regard, the present work introduces a novel method that utilizes an HMD in a VR soccer simulation to assess players' VEA within a realistic in-game situation. Furthermore, in the HCI domain, this work provides insights related to the VE's design choices, the importance of choosing the correct input device for interacting with the virtual world, and the corresponding effect of the perceived sense of Presence in the VEA performance of the athletes. This is done to provide a reference for future researchers and VR developers that may be interested in designing solutions for VR-based VEA training.

### **3.2 Defining READ-THE-GAME as a measurable skill**

Managers widely use many terms for describing the player's performance and aptitudes regarding their motor and cognitive skills. When it comes to pointing at a player's capacity to grasp the big picture of the game, anticipating other player's actions in a sort of future-teller fashion with optimal decision-making, managers often describe it as the capacity to Read-the-Game.

The terminology is present in soccer practitioners' daily jargon, and the rough idea of what it refers to is agreed upon by most experts. However, the concrete definition of the term and which elements are required to train to achieve a high level of such capacity is less clear and needs further clarification.

The term Read-the-Game was first defined as a "player's ability to anticipate future events from early components of an action sequence, which is an integral part of skilled soccer performance" [2]. This definition goes well in line with professional-level soccer managers' perception, as they tend to describe center backs and center midfield players as more proficient in their skill to Read-the-Game [22]. Considering that center backs are required to anticipate the attacking team always, and center midfielders are the backbone connection between attackers and defenders, these positions will probably rely more frequently and heavily upon their anticipatory skills.

Besides the mental capacity to remain one step ahead of the game, the Read-the-Game skill also was associated with better physical performance. More specifically, a better capacity to Read-the-Game has been linked with lower fatigue overall, as it optimizes movement and positioning, diminishing unnecessary physical loads like running during an extenuating soccer match [28].

When it comes to a young player's development, the skill is used as a parameter to differentiate skilled from less-skilled athletes [29]. Objectively defining the elements that comprise the skill to Read-the-Game is essential to optimize youth players' training protocols. In this regard, sports scientists pointed at a group of necessary abilities paramount to both anticipation and decision making. These abilities point at the brain's capacity to obtain useful contextual information based on visual information [30]. In other words, these are the perceptual-cognitive skills needed for the Read-the-Game skill. Accordingly, we can divide the skill into four fundamental abilities:

- *Advanced cue utilization (visual).*
- *Pattern recall and recognition (cognitive).*
- *Visual search strategies (visual).*
- *Knowledge of situational probabilities (cognitive).*

Even if it is hard to measure the Read-the-Game skill with one simplified parameter, it is possible to evaluate the four sub-elements introduced above individually. These four abilities can be further grouped into two sub-groups; one is the cognitive intensive group, which relies heavily upon memory recollection of learned strategies and behavior. The other group is the visual group, which relies intensively on immediate visual exploration and pattern recognition. The latter compendium of skills is better known in the sports research community as the Visual Exploratory Activity (VEA), and this is the main object of interest of the present thesis. In the following section, VEA's definition, elements, and method for measuring it will be provided.



### **3.3 READ-THE-GAME and Visual Exploratory Activity (VEA) relationship**

To successfully perform an action with the ball, soccer players must actively rely on visual exploration. To adequately scan their surroundings, players need to move their body, eyes, and head continuously and effectively [31] [32]. This activity is better known as the Visual Exploratory Activity (VEA), which 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 or other environmental objects or events relevant to the carrying out of a subsequent action with the ball" [33]. In other words, players utilize the visual information extracted during their VEA for better adapting their actions and movements to opportunities that may arise during the game by checking their surroundings [34]. To better understand the player's VEA, it is necessary to pay attention to their eye fixation, head, neck, and body rotation more in-depth [16] [17].

Regarding eye fixations, previous research suggested that more skilled players exhibit a distinctively different VEA pattern when compared to novices, presenting more eye fixations with less duration in a different sequence while searching toward different places with more varied informative locations [35]. Therefore, experts are expected to engage in VEA more effectively, optimizing the processing of the obtained visual information, leading to an optimal perception-action coupling [36].

A significant amount of effort has been dedicated to quantifying the VEA of soccer players by utilizing eye-movement registration technology with pre-recorded matches [6]. However, none of these works employed interactive open-play situations, in which the player is required to actively engage in realistic movements proper of the intrinsic soccer game dynamics. Aiming to fill this gap, more recent exploratory work focused on utilizing wearable

eye-tracking glasses during real-world football match play, gathering the eye-fixation duration and objects of interest [37].

While using real match situations instead of a screen helps present the complex dynamics inherent to real performance, each player experiences different unique and non-reproducible in-game circumstances, making it harder to compare variables and performance between subjects. Hence, on one side, there are works based on displays that allow reproducibility but low interaction. On the other, we see real-game studies with high action-perception coupling demands but low/difficult reproducibility of experimental conditions between subjects. This work aims to solve both types of approach's weaknesses by utilizing a VR simulation while providing a highly interactive in-game situation under controlled/reproducible experimental conditions.

Regarding head, neck, and body rotation, it is known that the human field of view covers roughly  $190^\circ$  degrees with both eyes, of which  $120^\circ$  is covered by binocular vision [18]. What is more, only about  $2^\circ$  of the field of view provides high-resolution vision in the center of the eye, where we see things clearly and meaningfully with high foveal cognitive load, and  $4^\circ$  with low foveal load [19] [20]. Consequently, rotational motions about the player's pivot are needed to cover a wider area for a better VEA. Despite this fact, we found a sensitive lack of research works focusing on this crucial element [6] [21]. In the current work available, it was suggested that a higher frequency of head movements increments the probability of completing a pass to a teammate. The mentioned study used a 10-second window before ball possession [38]. More recent work utilized inertial measurement units (IMUs) for measuring the rate and range of VEA engaged focusing on the player's head excursion; in other words, how much of the area is covered by the head rotation before receiving the ball in a real 11vs11 match [13]. The head-

mounted IMU utilized in the research work mentioned above was validated previously for this purpose [39].

The referred study showed exciting implications, such as the higher probability of making a successful pass forward towards the goal direction when the player presents a higher than average head turn frequency and head turn excursion before receiving the ball [13]. However, since this data was taken during live play, each player faced different match experiences. Therefore, data obtained with players under the same conditions for meaningful performance comparison is missing.

Considering the central role that rotational movements of the head and body play to explore our world visually [40], coupled with the domain-specific relevance that it has [41], it is surprising not to find works that study the player's head excursion behavior under controlled conditions [6]. This dissertation will implement a technological approach for assessing players' head excursion concerning their VEA under controlled conditions utilizing a fully interactive VR soccer simulation to fill this void.

Now that we defined the cognitive and visual (VEA) elements that comprise the Read-the-Game skill and further clarified the main sub-elements of the VEA, the whole concept can be schematized as seen in Fig. 1.

The methodology for obtaining the player's head rotational movements and its assessment will be introduced in the following sub-section 3.3.2.

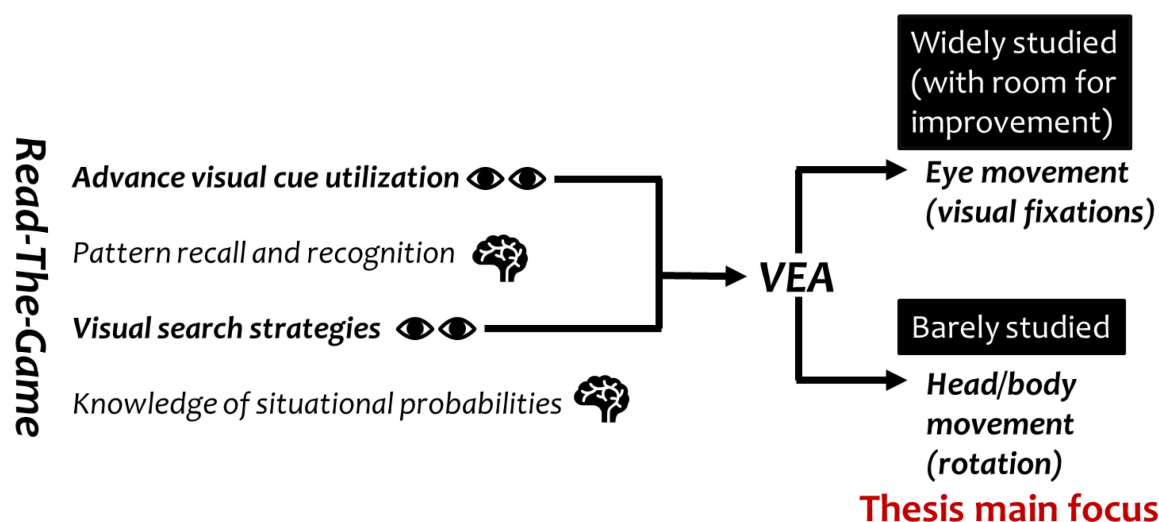


Figure 3.1. Representative schematic diagram of the Read-the-Game skill as defined in this dissertation.

### 3.3.1 Full body immersive VR

As we know it today, virtual reality has been researched and developed extensively since the 1980s, with sophisticated implementations considering the technical limitations of that time [42]. One of the main appeal points of the technology is the capacity it has of pulling the user into a vivid representation of an artificially generated world that will feel "real" to the observer in proportion to the system capacity to provide an immersive feeling. Immersion can be identified as an objective property of a system, being stronger or weaker depending on its capacity to provide natural sensorimotor contingencies for human perceptual modalities [43]. Thus, full-body interaction, which allows the user to engage in perceptual action with the whole body, like reaching out with the arms, moving around, or kicking a virtual ball with their legs, will provide a higher immersion than a system that only allowed to stare at a screen statically [44].

Sport-specific research has suggested that including the body's natural movement is essential for providing a superior sense of immersion. More immersion subsequently improves

the sense of Presence perceived by the player [45] [46]. Furthermore, the athlete's perception of their playing capabilities concerning the VE physical properties will determine the action decision-making process. In this regard, previous research established the importance of both geometric properties of the VE and the user's kinetic affordances that affected the player's in-game decisions [47] [48].

Considering the relevance of including full-body immersive interaction in sports training VR simulators, we implement a system with a natural mapping motion capturing controller. A poor design choice about the input implementation can negatively affect the system's capacity to promote realistic athlete's behavior. Hence, to evaluate and validate the proposed system implementation, we compare different controllers' effect within our VEA assessment VR simulation.

We will explain the motion capturing system design criteria, implementation, and technical aspects in section 4.5.

### **3.3.2 Measuring VEA with an HMD**

Potential play choices constantly surround soccer players. A term used to describe these opportunities is also termed "affordances" [49] [32]. Consequently, they are required to effectively move their heads, body, and eyes to cover the maximum perceivable area on the pitch [6]. Furthermore, it was suggested that players who engage in the higher exploratory excursion are more likely to utilize their affordances in their surroundings more effectively [13]. With this in mind, a system that measures total head excursions' magnitude was designed, focusing on the total rotational motion about the player's pivot.

However, to obtain and measure the player's VEA based on the head and body rotation, there is one primary requirement. The system must be capable of registering the player's head

excursion in the 360° covering the entire Field of Regard (FOR). However, most laboratory-based studies focus only on eye fixations, ignoring the head rotation intentionally while projecting the visual stimuli on a screen utilizing static imagery [50]. One of the main reasons for this trend is the technological limitation of utilizing 2D display screens as the presentation medium. To solve this, we chose to use VR technology, which allows total control over the VE while offering a 360° area for stimuli presentation. Chapter 4 will further explain the advantage of utilizing VR technology as a sports perceptual training medium.

Considering the type of movements that a soccer player makes to rotate their bodies in search of visual information, avoiding adding extra weight to the player was important. There are two main design options; one is CAVE systems (Cave Automatic Virtual Environment), a projection-based VR display solution providing an immersive room where walls, floor, and ceiling act as giant displays. These VR systems can be implemented without requiring extra weight as in the form of wearables. However, this approach requires expensive equipment, a semi-permanent installation with considerable space requirements [51]. On the other hand, we have Head-Mounted Displays (HMD), which also offer stereovision with an adaptive viewpoint at a lower cost, without a complicated setup, and deployable in more limited spaces. Considering that we wanted to provide a portable and accessible solution to practitioners and researchers alike, we chose the HMD for designing our system.

The hardware chosen for this project was the Oculus Rift Consumer Version 1 (CV1). When designing this solution, the CV1 was the lightest HMD available with good resolution and head tracking capabilities, weighing 470 grams. In comparison, the next potential candidate at the time was the HTC Vive, weighing 555 grams. Both headsets offered the same refresh rate at 90 Hz and Field of View (FOV) at 110° [52]. Therefore we chose the less bulky option based on its weight and ergonomics.

To extract the head direction of the HMD, we extract and utilize the Euler angles from the head orientation of the player on a frame by frame basis. Based on Euler's rotation theorem, the 3D orientation can be obtained with the single rotation in one axis anchored to the origin. The corresponding mapping of the mentioned axis-angle over the space of unit quaternions can be expressed as:

$$q(v, \theta) = \left( \cos\left(\frac{\theta}{2}\right), v_x \sin\left(\frac{\theta}{2}\right), v_y \sin\left(\frac{\theta}{2}\right), v_z \sin\left(\frac{\theta}{2}\right) \right) \quad (3.1)$$

In Eq. 3.1,  $q(v, \theta)$  is a unit length quaternion corresponding to the radian  $\theta$  rotation about the unit-length axis vector  $v = (v_x, v_y, v_z)$  [53]. Therefore, we obtain the coordinates from the yaw, pitch, and roll rotations about the horizontal axis to represent the player's head excursion wearing the HMD.

For the CV1, the headset rotation is maintained as a unit quaternion, positive counter-clockwise, and obtainable in yaw-pitch-roll form as well. The pitch rotation occurs on the X-axis about the headset pivot, positive if pitching up and negative when pitching down. Yaw refers to the Y-axis rotation, positive if turning the head left and negative when turning right. Finally, roll refers to the Z-axis's rotational motion, being positive by tilting the headset to the left and negative when tilting to the right [54]. The system logs the Euler rotational angles on a frame by frame basis, saving them in a CSV file for analysis. A visual representation of the yaw, pitch, and roll motions registered with the HMD is presented in Fig 2.

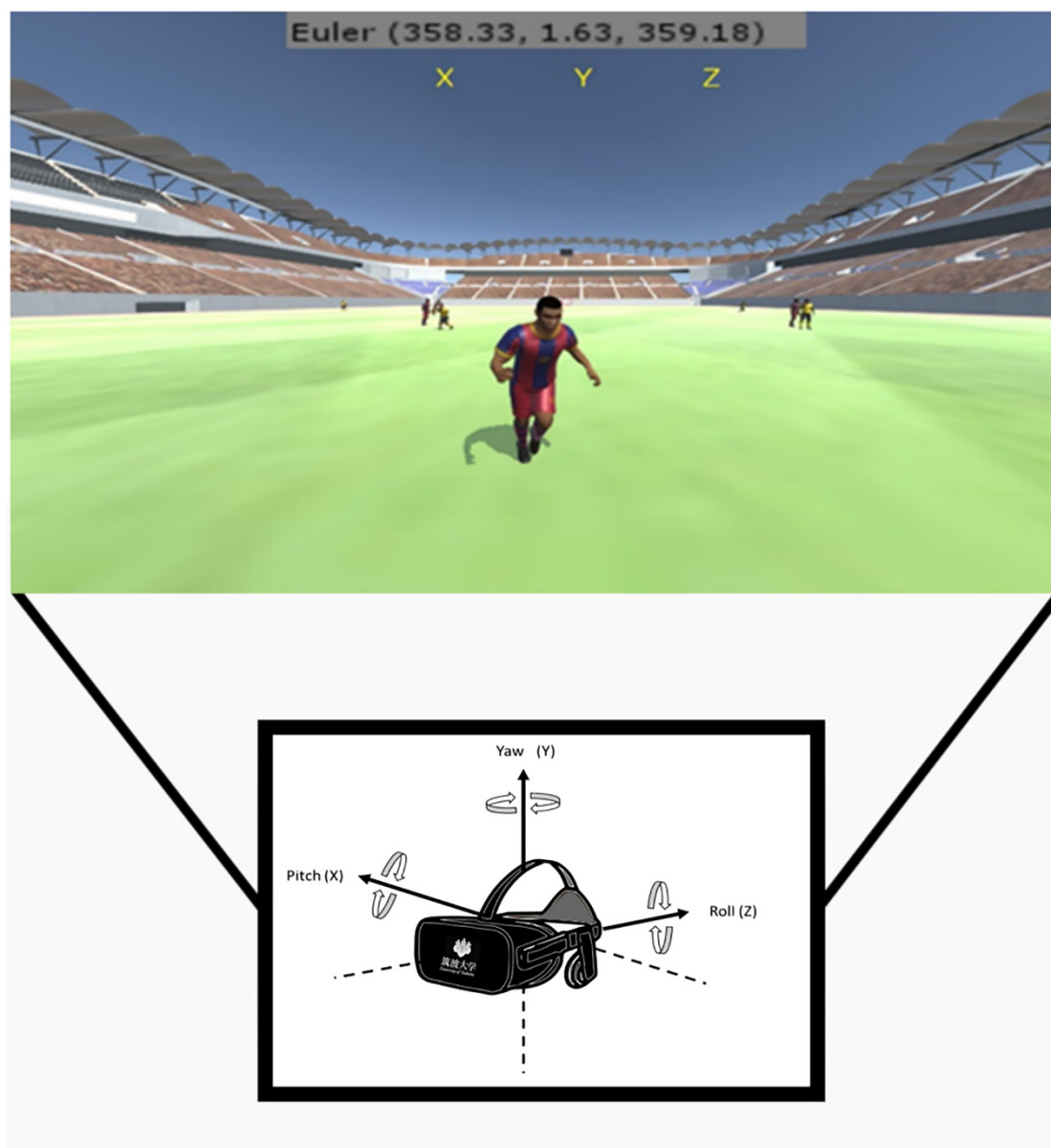


Figure 3.2. Yaw, pitch, and roll Euler angles were obtained from the HMD. The image's top represents the VE's player view, with the corresponding X, Y, and Z Euler angles overlaid for monitoring purposes. It is essential to clarify that the user cannot see the overlaid Euler angles during the simulation.

### 3.3.3 VEA zonal division

This system is the first to measure the player's VEA performance in the function of their head excursion in VR. Hence, it was required first to define the method and criteria for



measuring such behavior. For doing so, the FoR surrounding the player was divided into key zones of interest. This zonal division simplifies the VEA analysis and promotes more precise comparisons between players, with an exact visual representation of their behavior.

The classification given to the head excursion patterns used for defining the referential zones was based on seminal work [33]. We focus on two main types of explorations:

**Long Exploratory Activity:** VEA in which the player's head orientation is for one second or more facing away from the ball location.

**180-Degree Exploratory Activity:** The head of the player is positioned looking towards the opposite direction from the ball's location, as perceived through an axis from the ball through the body and over the player's pivot.

Based on the two referential types of exploratory activity introduced above, the zonal division was constructed as follows:

**Zone 1:** The zone refers to the area between  $45^\circ$  and  $-45^\circ$  ( $315^\circ$ ) to the player's front. This is where the player is looking straight forward, and the ball enters his FoV.

**Zone 2:** This zone is the area between  $45^\circ$  and  $90^\circ$  to the right and  $-45^\circ$  ( $315^\circ$ ) and  $-90^\circ$  ( $270^\circ$ ) to the left of the user. To explore this area, the player must look away from the ball, rotating his head and/or body to either side engaging in long exploratory activity.

**Zone 3:** This area is located at  $>90^\circ$  and  $<270^\circ$  clockwise, representing the 180-degree exploratory activity. To visually explore this area, the player must look in the diametrically opposite direction from the ball location. In other words, is the zone located on the back of the player.

The player's head excursion-based VEA performance is measured by calculating the cumulative total percentage of frames the player stays looking at, either Zone 2 or Zone 3, before making a passing decision. For the sake of simplification, we will refer to this percentage as the VEA score from now on. The formula for obtaining the VEA score can be written as follows:

$$\text{VEA score} = \frac{\text{frames}_{z2} + \text{frames}_{z3}}{\text{frames}_{\text{total}}} \times 100 \quad (3.2)$$

Where:

**frames<sub>z2</sub>:** Sum of frames the user spends looking at Zone 2 from the beginning of the test scene until the player makes a ball pass.

**frames<sub>z3</sub>:** Sum of frames the user spends looking at Zone 3 from the beginning of the test scene until the player makes a ball pass.

**frames<sub>total</sub>:** The total sum of frames displayed from the beginning of the test scene until the player makes a ball pass.

Note: The measuring reference time is defined by the frequency at which consecutive images called frames appear on the HMD. In other words, the effective frame rate is the time measuring unit utilized for assessing the VEA, beginning to count from the first frame to be displayed at the start of the test scene.

A graphic representation of the zonal division proposed here can be seen in Fig 3.3.

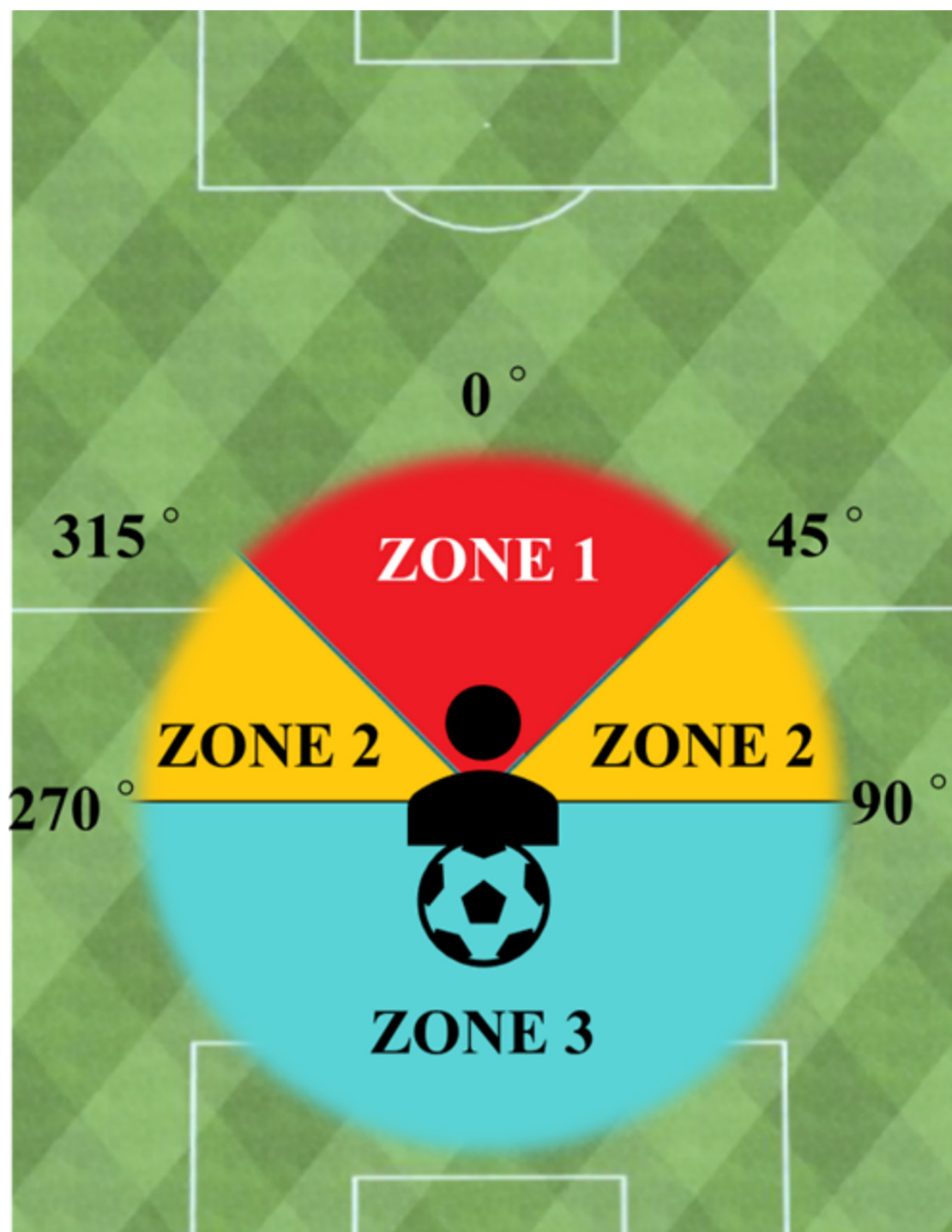


Figure 3.3. The zonal division is used as a reference for obtaining the rotation-based visual exploratory performance, defined in this work as a VEA score. The VEA score is obtained by calculating the cumulative percentage of total frames the player spends looking towards Zone 2 and Zone 3 before making a pass with the ball.

## **CHAPTER 4**

### **READ-THE-GAME SKILL ASSESSMENT IN VIRTUAL REALITY (VR)**

#### **4.1 VR as a sports perceptual training medium**

Virtual reality has gained popularity in recent years due to its potential for skill-based training under controlled conditions [55]. One of the main reasons behind the increasing adoption of this technology is that it can provide spatio-temporal constraints specific to team ball sports. As a result, it elicits a higher sense of immersion than training solutions based on 2D imagery [56].

There are essential elements relevant to the game that are rather hard to control with traditional training protocols. More specifically, elements such as the trajectory of the players or the ball are essential components related to the whole game dynamic, and at the same time, serve as relevant cues that players act upon according to their level of expertise [57]. In conventional training, real players must position themselves and simulate possible in-game situations with precisely coordinated action. In reality, this approach imposes unnecessary extra physical and cognitive loads on the players [58], more so if the training drill aims to develop the skills of one or two specific player positions but requires the rest of the team to cooperate in the training session. VR makes it possible to easily modify these cues while registering the athletes' movements and visual activity for in-depth analysis.

The advantage of VR in team sports has been proven already in different disciplines for measuring player's anticipatory skills, such as Rugby and Handball [59]. In Handball, for example, it was used to analyze the player's perceptual ability regarding ball interception of goalkeepers [60]. Researchers also proved the use of VR to assess cricket players' anticipatory

skills while suggesting that it was better suited as a technology than conventional video, given the more significant number of perceptual elements present in a VR simulation [61].

As expected, there are applications specific to soccer. Previous work showed that VR could be used for assessing and possibly training the goalkeeper's ability to intercept the incoming ball with their hands [62]. Another work employed VR for measuring the player's movement when heading a ball, modifying the mid-flight ball trajectory to assess the underlying process related to ball interception [63].

A recent study proved the construct validity of a soccer VR simulator adopted by some professional teams regarding training solutions. Professional players out-performed both novice and academy players in most VR drill exercises [64].

Considering the advantages and potential of the technology shown by existing literature, we decided to adopt VR as the testbed technology to develop a training solution with high action-perception coupling. In this regard, another advantage of VR over traditional video is the higher sense of immersion provided, with multisensory engagement that positively affects the user's sense of Presence. In the following section, we will explain what makes a VR simulation immersive and why the sense of Presence is an essential indicator of the whole experience.

## **4.2 Full body immersive VR and sense of Presence relationship**

In entertainment-grade VR experiences, the system's design approach can take as many liberties as needed to provide engagement and be "fun." However, in the case of training and performance assessment simulators, specific requirements need to be fulfilled. For instance, good VR simulators should have adequate fidelity levels, where the VR experience accurately reproduces the real-life scenario's baseline behavior [65]. Fidelity can be cataloged into physical, psychological, affective, and biomechanical fidelity. In this regard, it was suggested that in a

sports context, there is a positive correlation between the congruency of these elements and the potential effect in real-life performance [66].

VR systems must also provide validity, defined by the extent to which the VR simulation represents the intended task's core elements [66]. Validity can be divided into face validity, which is the user's subjective perception regarding how "realistic" the VE is. Some indicators suggest a relationship between face validity and plausibility (more on plausibility later) [67]. There is also construct validity, which is to what extent the simulation reproduces the totality of intended task elements [68].

There are various definitions of immersion, but for the sake of consistency, we will refer to immersion as the technical capacity of a given simulation to provide physical stimuli to the sensory system and how sensitive is the simulation to user inputs. This definition goes in line with that proposed by previous work [68] [69]. Regarding immersion levels, it was suggested that "The level of immersion is determined by the number and range of sensory and motor channels connected to the virtual environment. Furthermore, immersion level is influenced by the extent and fidelity of sensory stimulation and responsiveness to motor inputs (for example, head and body movement, and hand gestures to make commands)" [70]. In other words, full-body interaction with realistic kinetic perceptual stimuli will provide more immersion than systems based on traditional directional controller and button press-based input options.

While immersion refers to the user's input and stimuli in the VE in general, the psychological byproduct that describes the sensation of existing inside the virtual world is known as Presence [71] [72]. The sense of Presence can be defined as "the perceptual illusion of no mediation" [73]. A more extended definition well adopted by the research community is "the sense of being in a virtual space that is presented by technological means" [74] [75] [76].

Furthermore, two components have been suggested to be comprised in the Presence construct. One is place illusion, which is the perceived illusion of really being and existing inside the VE. The other one is plausibility, defined by the degree to which the user feels that the depicted situation inside the VE is happening in reality, related to the face validity defined above. Both elements, place illusion and plausibility, will determine to what degree the user behaves inside the VE compared to reality [67] [68] [69]. Regarding skill transfer, a high level of Presence has been related to effective training effects and increased learning experience, linked to a higher overall immersion [77].

Considering the relevance of Presence in validating VR training systems' effectiveness, we evaluate the elicited sense of Presence of the proposed soccer simulation. In the following section, we will explain how we measure Presence with a psychometric questionnaire tool.

### **4.3 Measuring Presence in VR**

The level of Presence can be assumed to be an individual subjective perception that varies from person to person according to their particular experience inside the VE. As such, the most common method of measuring Presence is through post-test psychometric questionnaires.

There are various questionnaires with different metrics and items developed for such purpose [78]. One of the most widely adopted is the famous Slater, Usoh, and Steed (SUS) questionnaire [79], which consider both external (i.e., quality of the displays, media, realism, and interactiveness) and internal (i.e., subjective perception unique to the individual) factors.

Similarly, another relevant questionnaire is the Presence Questionnaire (PQ) [76] [80]. The PQ defined four factors resulting from a component analysis, identifying Involvement, Adaptation/Immersion, Sensory Fidelity, and Interface Quality as valid descriptors of the sense of Presence in VR. Both SUS and PQ questionnaires share common elements of interest for measuring the Presence construct [81].

A third Questionnaire that builds upon knowledge provided by both SUS and PQ proponents is the Igroup Presence Questionnaire (IPQ) [82]. The creators of the IPQ performed an extensive factor analysis with over 500 users that resulted in the identification of three independent factors (sub-scales) with a general item (not a sub-scale) for the Presence construct [74] [82]. The three identified factors are:

**Spatial Presence:** This is the sensation perceived as being physically present in the virtual world.



**Involvement:** How much attention is being dedicated to the VE and how much involved the user feels.

**Experienced Realism:** The degree of realism felt by the user from a subjective perspective.

The third general term refers to the overall sensation of "being there" as perceived by the user. The general item has high loadings on the other three sub-scales.

Rigorous factor analysis, like the one described above, is essential for validating psychometric questionnaires' reliability. Amongst the questionnaires available, the only two sufficiently validated and determined to be statistically robust given their overall composition are the PQ and IPQ questionnaires [83].

For the present work, we considered both the reliability and availability of the questionnaire in various languages. Considering that the proposed system was first evaluated with Japanese players, we required a questionnaire in their mother tongue. In this particular, the IPQ questionnaire has various translations validated as consistent with the original [84]. The IPQ is readily available in Japanese, so considering its robustness and language convenience, we selected it as the ideal candidate for the present study.

The copy of the original Japanese questionnaire implemented in our study can be observed in Fig 4.

QUESTIONNAIRE			
VR Soccer Trainer			
<i>Test Subject Profile</i>			
No:	年齢:	サッカーの経験年数:	
主なポジション:			
A. ゴールキーパー	B. ディフェンダー	C. ミッドフィルダー	D. フォワード
サッカーのレベル:			
A. 初心者	B. アマチュア	C. セミプロ	D. プロ
以下の質問に対して、自分が最も近いと思った選択肢を選んでください。			
1. コンピューターで作られた世界の中で、私はそこにいる感じがした。			
1	2	3	4 5 6 7
全くなし			非常に強い
2. 私は仮想世界に取り囲まれている感じがした。			
1	2	3	4 5 6 7
全くその通りでない			全くその通り
3. 私はただ単に映像を見ているような感じがした。			
1	2	3	4 5 6 7
全くその通りでない			全くその通り
4. 私は仮想空間にいる気がしなかった。			
1	2	3	4 5 6 7
気がしなかった			気がした。
5. 私は何かを外部から操作しているのではなく、仮想空間の中で振る舞っているような感じがした。			
1	2	3	4 5 6 7
全くその通りでない			全くその通り
6. 私は仮想空間の中に居合わせているように感じた。			
1	2	3	4 5 6 7
全くその通りでない			全くその通り
7. あなたは、仮想世界を通過して移動して行く間に、周りの現実世界をどのくらい意識していましたか。(例えば物音、室温、他の人間など)			
1	2	3	4 5 6 7
極度に意識した		普通に意識した	意識しなかった

Figure 4.1.1 Japanese translation of the IPQ questionnaire (page 1).

8. 私は、現実環境をもはや意識しなかった。	
1 2 3 4 5 6 7	
全くその通りでない 全くその通り	
9. 私は未だ現実環境を注意していた。	
1 2 3 4 5 6 7	
全くその通りでない 全くその通り	
10. 私は仮想世界によって完全に魅了されていた。	
1 2 3 4 5 6 7	
全くその通りでない 全くその通り	
11. あなたは、仮想世界がどのくらい現実のように見えましたか。	
1 2 3 4 5 6 7	
全くの現実のよう 全くの現実のようでない	
12. あなたの仮想環境の経験は、あなたの現実環境の経験とどのくらい似ていましたか	
1 2 3 4 5 6 7	
全くの似ていなかった 多少似ていた 全く似ていた	
13. あなたには仮想世界がどのくらい現実のように見えましたか？	
1 2 3 4 5 6 7	
想像された世界のよう 現実世界と区別ができない	
14. 私には現実世界よりも仮想世界の方がより現実に見えた。	
1 2 3 4 5 6 7	
全くその通りでない 全くその通り	
コメントや提案があればお書きください。	

Figure 4.1.2 Japanese translation of the IPQ questionnaire (page 2).

#### **4.4 Building a VE for level based VEA assessment**

The VE construction was done aiming to provide a high level of Presence to the players. We considered elements such as scale fidelity, ensuring that the objects perceived in the VE are equivalent in size to the real world, and reasonable accuracy of the auditory stimuli as a faithful representation of the real sound perceived in a soccer match.

Instead of utilizing 360° videos, we chose to implement a Computer Graphics (CG) solution. The reason behind this design choice is that CG graphics allow a bigger degree of interactivity with the user when compared to pre-recorded videos. In recent work, CG-based VR reported a higher level of Presence than 360-VR, which correspondingly showed a higher level than TV-based imagery [85]. These findings go in line with previous findings suggesting that a VR simulation should be as "real" as the intended task requires it to be [68], and graphic realism is inconsequential in comparison to task-specific elements [86] such as interacting with the ball in the case of our simulation.

##### **4.4.1 VE scale and sound**

To accurately portray the sensation of being on a soccer pitch, the VE content was designed using real-world measures for each element. The development environment of choice was Unity 3D as it provides good visualization and light conditions rendering, which facilitates modeling 3D spatial geometry with accuracy [87].

The model used for the soccer stadium was the Kashima Antlers team stadium (Kashima Soccer Stadium) SketchUp model (.skp) [88], converted to a one-to-one scale to the dimensions in real life. Unity 3D employs a scaling system in which one size unit inside the game engine is equivalent to one meter in real life, commonly known as unity units. Accordingly, we straightforwardly scaled the model by referring to the soccer pitch's real dimensions.

The main reason for choosing the Kashima Soccer Stadium was to provide a venue familiar to the players. Since the prospective participants were Japanese university players studying in Ibaraki, which also is where the Kashima Antlers' stadium is located, we thought it was the best choice. The scaled model of the stadium imported inside Unity 3D can be observed in Fig 4.2.

The elements inside the pitch were also sized with utmost care. Based on the FIFA standard measures of the pitch elements [89], we constructed a faithful representation of a professional stadium in VR. For example, the goal post measured inside Unity 3D with the corresponding federated measures converted to unity units can be seen in Fig 4.3.

The sound was another element taken into consideration. In competitive sports, the game's atmosphere, the shouting crowds, and players' shoutings can make a difference in players' performance and engagement. The effect of the crowd can produce a positive effect on the home team performance [90]. Furthermore, the effect of the chanting crowd can improve performance based on motivation. It can also negatively affect performance due to over conservative play related to high pressure [91].

Thus, authentic ambiance sound was recorded from a crowded Kashima Antlers game to reproduce it inside the VE. It is good to note that, despite being out of this study's scope, we consider that VR can serve as a useful tool for testing the auditory influence and validity of the "home advantage" in sports.



Figure 4.2. Kashima Soccer Stadium model imported and scaled in the Unity 3D editor.

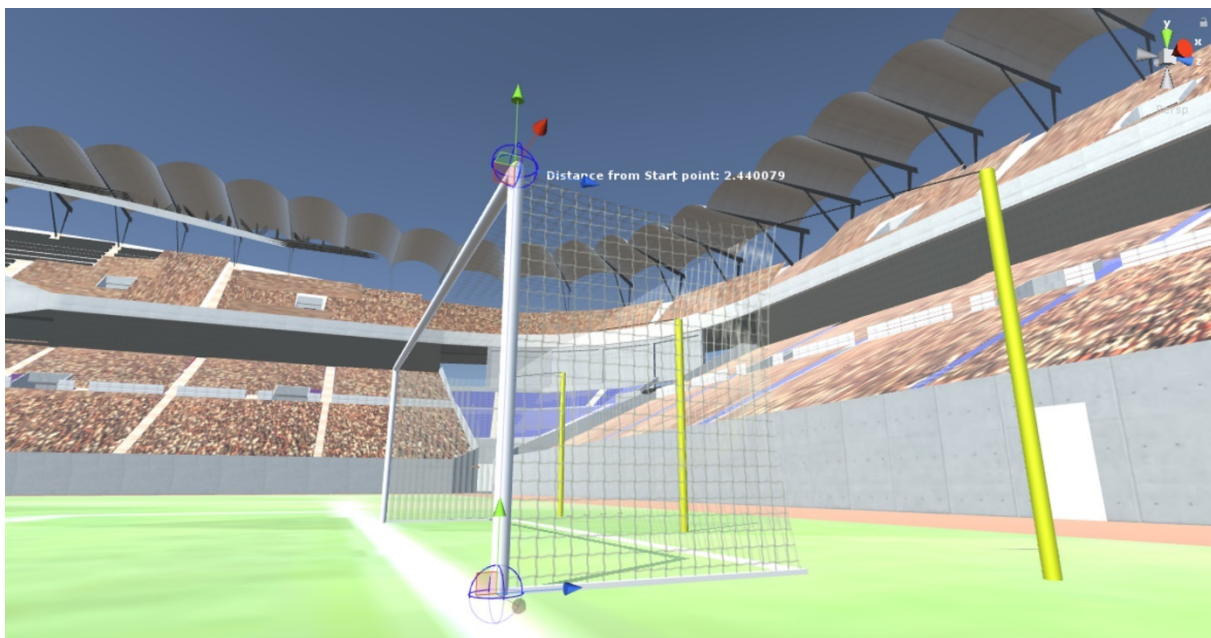


Figure 4.3. The goal post measures 2.44 m in real life, according to FIFA, here we see the converted size to unity units. The distance of 2.440079 (unity units) in the image is the height of the post measured from the ground of the pitch.

#### **4.4.2 VE scene content**

The workflow of the simulator was constructed considering the adequation of the player to the VE. Considering that the present VR system was mainly intended to validate our hypothesis, it was required to avoid the novelty factor by correctly introducing the players to the VE. Consequently, two tutorial scenes containing the basic interaction mechanisms were prepared and experienced before the experimental run.

The scenes contained in the simulator were as follows:

"Main Menu" Scene: This is the first view of the user when wearing the HMD. He encounters a radial menu, depicting the two tutorials followed by the experimental scene arranged from left to right. The player is required to access them in order from left to right in concordance. The user can see a referential pointer projected from the center eye of the HMD. The referential pointer serves as a visual guide to the users, so they know exactly where the center of their FoV is located. The user accesses each scene by looking at them for five seconds. The simulation returns automatically to this menu after each scene task is completed. A picture depicting the Main Menu Scene can be observed in Fig 4.4.

"Look at the Spheres" scene: The first tutorial scene is intended to acclimate the user with the HMD and the look-at mechanics used throughout the simulation. The scene comprises an empty stadium without players or the public, and four semi-transparent spheres surround the subject. The user must search for the spheres, which change into solid blue color once the gaze pointer successfully hits them. The user's view of the scene can be seen in Fig 4.5.

"Pass the Ball" scene: Just like the first tutorial scene, the user finds himself in the same empty stadium. However, this time there are three teammates with yellow/black uniforms and three rival models with red/blue uniforms standing in three different positions surrounding the user. This scene aims to get the user used to the ball passing mechanics and the players' CG

models. The user is supposed to pass the ball successfully to the three teammate player models. If the ball successfully reaches one teammate, his CG model disappears as a visual cue denoting success. If the user fails to direct the pass correctly, the ball reappears in front of the user. The user is required to repeat as many times as needed the passing action until successful passes to the three teammates are completed. The auditory feedback once again is that of an empty stadium with natural ambiance sound and empty seats. There are two input options for the passing mechanics, which will be further introduced in section 4.5. The Point of View (PoV) of the user at the moment of making the ball pass can be appreciated in Fig 4.6.

"Test" scene: This scene is intended to assess the user's head excursion while searching for a passing option under pressure from a rival player. The specific playing drill portrayed in the scene will be introduced in section 4.4.3. In this scene, the subject must make a passing decision before losing the ball to an upcoming rival. The total time available for the subject to complete the pass before losing the ball is 7 seconds. The subject is preemptively warned about the imperative necessity of a quick and effective decision before proceeding to this scene. This time, the chanting crowd's sound is present, and the public can be seen on the seats to elicit a competitive game sensation. The scene ends once the pass is completed or the ball possession is lost. The VEA of the user is logged and saved in a CSV file frame by frame until the ball pass occurs, with the method introduced in section 3.3.2. The view of the scene from the PoV of the subject can be seen in Fig 4.7.

The complete workflow of the simulation can be appreciated in Fig 4.8.



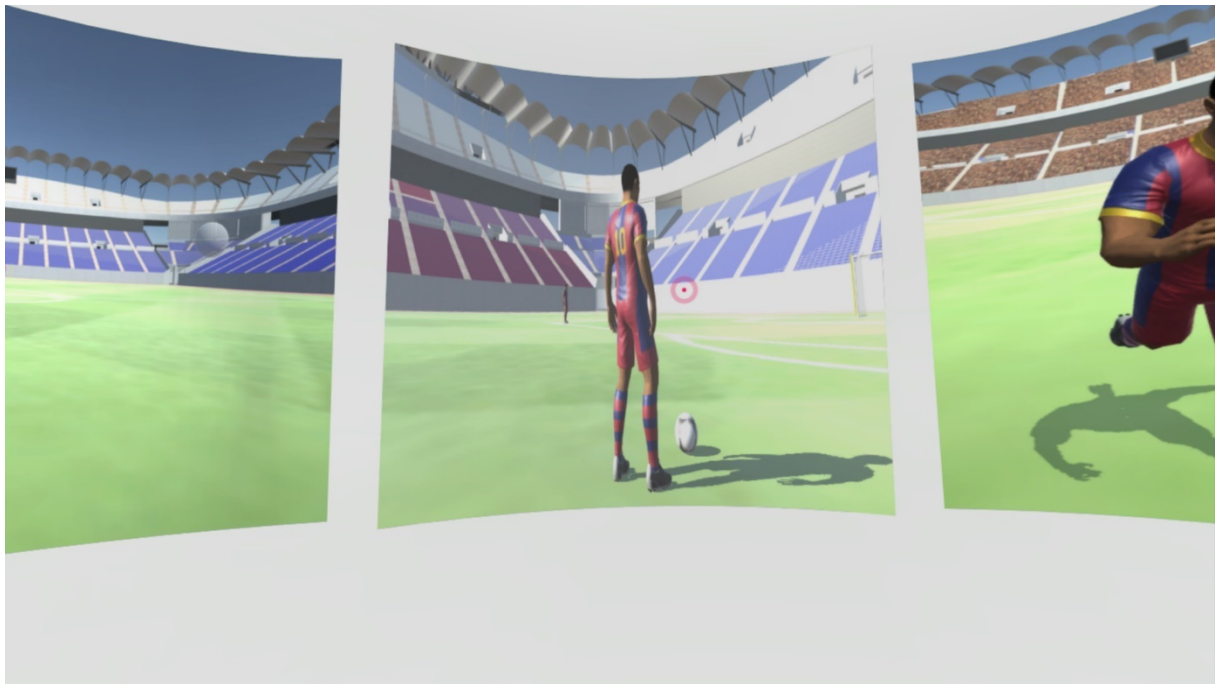


Figure 4.4. *Main Menu* scene view: The user accesses each scene from left to right by looking at them for five seconds. The simulation returns automatically to this menu after each scene task is completed.

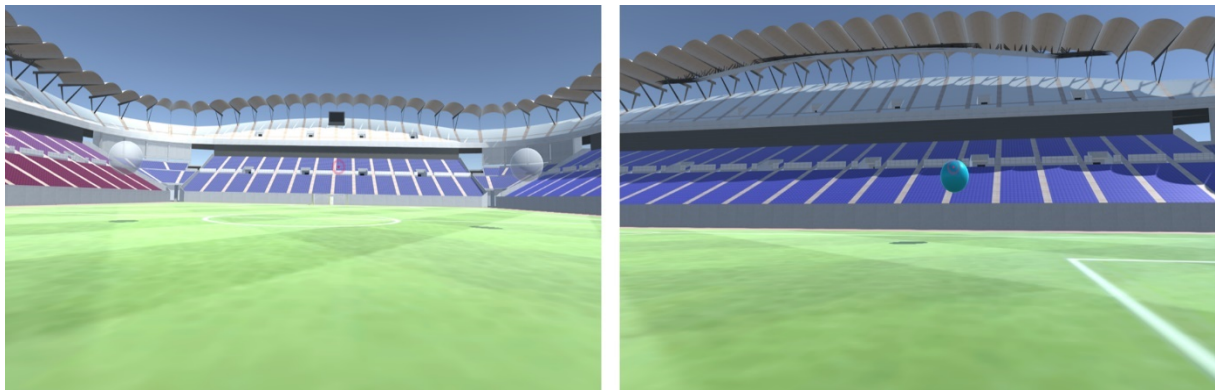


Figure 4.5. *Look at the Spheres* scene view: To the left, the translucent spheres can be seen in the periphery of the subject's FoV. On the right, a sphere is turning blue when the subject looks at it by directing the pointer with his/her head.



Figure 4.6. *Pass the Ball* scene view: The user practices the ball pass mechanics. One teammate with yellow/black uniform and one rival model with red/blue uniform can be observed together with the ongoing ball towards the teammate model.



Figure 4.7. *Test* scene view: The user looks at the incoming rival while searching for passing options. The head rotation-based VEA is logged frame by frame for post-analysis.

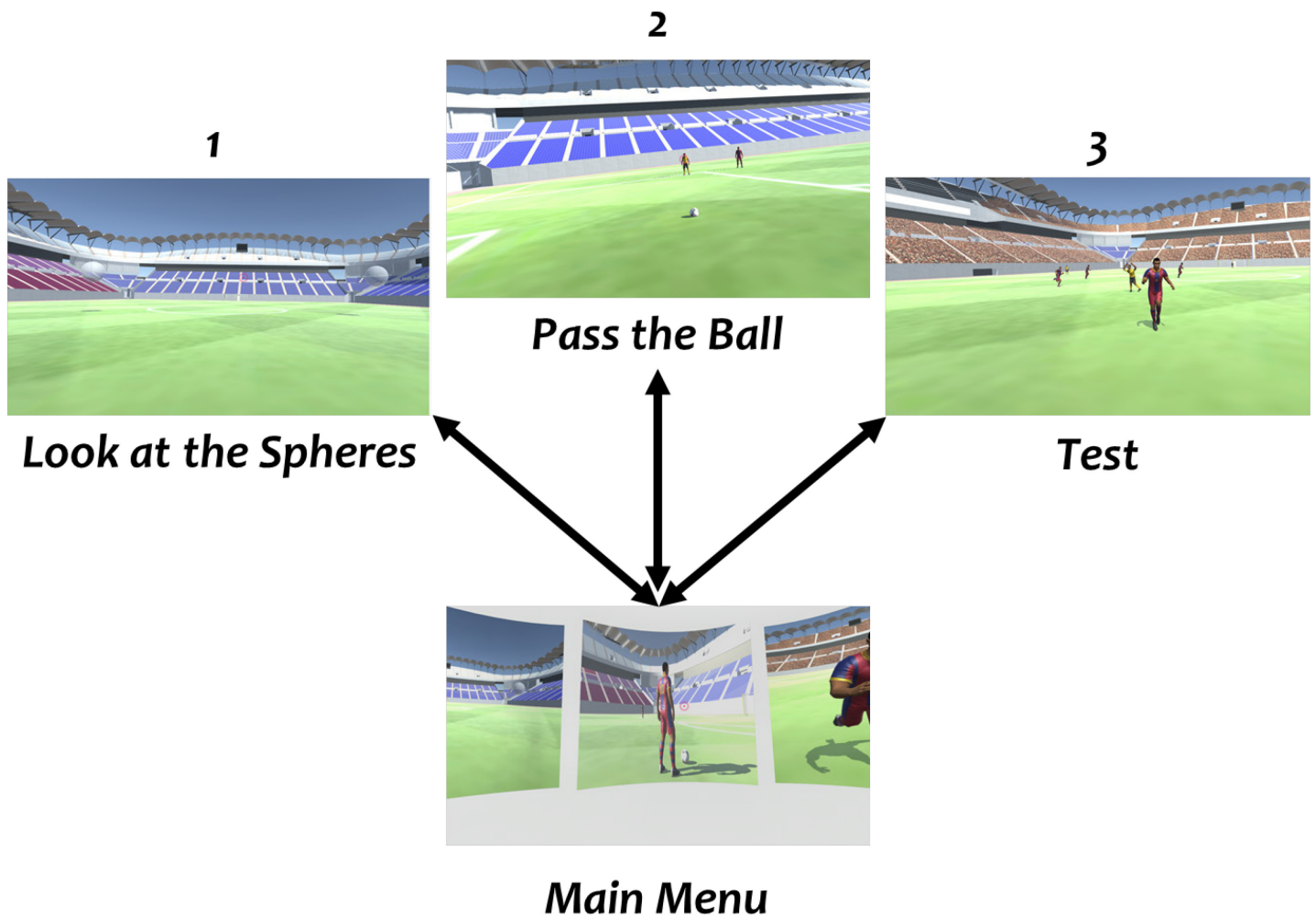


Figure 4.8. Simulation workflow: The subject starts the simulation from the *Main Menu*, accessing each scene in numerical order from one to three. Every time the task inside each scene is completed, the simulation returns to the menu scene.

### **4.4.3 Playing drill**

According to professional managers, the Read-the-Game skill is predominantly present and relevant in central defenders and center midfield players [3]. Thus, we considered it appropriate to portray a realistic in-game situation typical to these playing positions. Since the simulation was intended to stimulate VEA in the function of the head excursion, we carefully selected a playing drill typical to the positions mentioned above.

The drill was based on a standard practice used for training zonal defense strategies by professional coaches and is recommended and approved on the official Coach Manual published by the Fédération Internationale de Football Association (FIFA) [92]. The drill's name is "7 v 6 (8 v 6) game to work on regaining possession," in which seven players exert zonal pressure on the team in ball possession. The subject will start the simulation with ball possession, and the teammates are standing in his surroundings, waiting for a potential pass. The teammates are static while the rival team runs to cover possible passing options, difficulting the passing decision due to interception risk. One of the rival players is approximating quickly to the subject in ball possession and execute a sliding tackle once he is close enough to rob the ball. The player has a time window of seven seconds to make a pass before losing the ball. The criteria for choosing this specific time constraint are based on previous research that measured decision making and execution in real soccer game contexts utilizing the Game Performance Evaluation Tool (GPET) applied to youth players from the Spanish second division [93]. In that research, the presented game's time analysis showed that the game situations' average duration with sufficient technical and tactical significance was 8.52 seconds with a standard deviation of 5.28 seconds; ergo, the proposed 7 seconds for our in-game situation is well within the time range. In other words, a soccer match can be subdivided into concatenated short bursts of key moments lasting a few seconds, with each playing an essential role in the bigger picture of the

game. We focus on studying the player rotational VEA during one of such pivotal moments in the present work.

The teammate without any man-marking is located to the left of the user in the area comprised between  $-45^{\circ}$  ( $315^{\circ}$ ) and  $-90^{\circ}$  ( $270^{\circ}$ ) from the center of the player looking forward. Therefore, the subject must engage in wide VEA, exploring Zone 2 to see him.

Before the experiment, the content was also showcased to professor Koido Masaki, the University of Tsukuba soccer team coach, certified by the Japan Football Association (JFA).

To see the diagram representing the playing drill, refer to Fig 4.9.

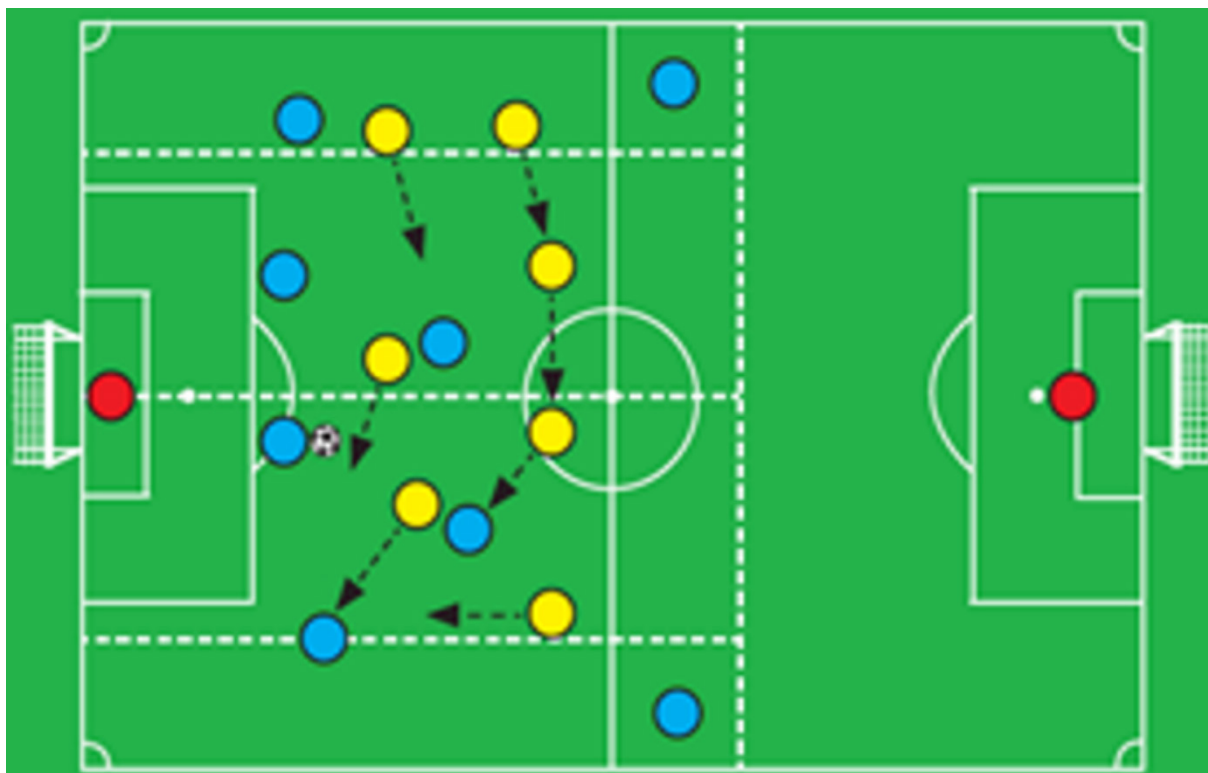


Figure 4.9. Play drill: 7 v 6 (8 v 6) game to work on regaining possession. The subject starts in ball possession, depicted in the image as the blue dot with the ball symbol. The rival team (yellow dots) moves in the arrows' direction, while the subject visually scans the area in his surroundings, searching for a passing option.



#### **4.5 Full body interaction**

The main action with the ball to be performed inside the proposed VE is a pass. Accordingly, the best input choice for the system was considered to provide the best immersion. When it comes to input control interfaces available for entertainment media and VR simulations, controllers can be defined about their "naturalness" or interactivity potential [94], known in the scientific community as naturally mapped control interfaces. The naturally mapped control interfaces can be divided into three categories or levels: First, we have kinesic natural mapping, using the player's body as a game controller. Then, there is incomplete tangible mapping, using a controller similar to a real object. Finally, we have realistic tangible mapping, using a controller or an object that directly relates to the real-life activity the game simulates [95].

Regarding the elicited sense of Presence provided by the controllers, all types of naturally mapped controllers can provide an adequate level of Presence if implemented correctly [95]. Keeping in mind the main task of passing the ball inside the VE, we chose the kinesic natural mapping, which perfectly fits the intended motion of kicking the ball with one's feet.

The selected hardware for the system was the Microsoft Kinect for Windows V2 motion-sensing controller. There is sufficient data from previous work that supports its usage in studies and systems involving motion tracking and gesture recognition [96], and it was proved its positive impact on Presence in Mixed Reality (MR) and VR simulations [97].

The database used for passing gesture recognition was created with Microsoft's Visual Gesture Builder (VGB) [98].

Eight volunteers were filmed using Kinect's camera while making various gestures taken from various angles. The gestures were proper of a soccer match, such as dribbling, jumping, passing, and shooting mixed with random movements. The video clips were then registered in the Kinect Studio software application and hand tagged with VGB for discriminating the

passing action from the rest. The hand-tagged clips then served for training the AdaBoost machine learning algorithm [99] for recognizing the passing action of the users inside the VE. The video clips were mirrored as well to increase the available training data further. The trained algorithm was tested with randomized gesture clips to assess its accuracy until no false positives nor false negatives occurred. One of the hand tagged clips in the VGB utilized for the training phase can be seen in Fig 4.10.

Once the training phase was complete, the resulting gesture database file (.gdb) was imported in unity for its implementation. A subject performing a pass in the VE can be seen as perceived by Kinect in Fig 4.11.

For validating the utilization of kinesic natural mapping in our system, we compared the effect of utilizing a traditional gamepad controller (Xbox One) in the elicited Presence. In the gamepad configuration, the pass is done by pressing one button, and then the ball pass occurs automatically towards the vector direction where the player is looking. Furthermore, we searched for possible correlations between the type of controller and VEA performance. In the following chapter, the results and corresponding statistical analysis will be introduced.

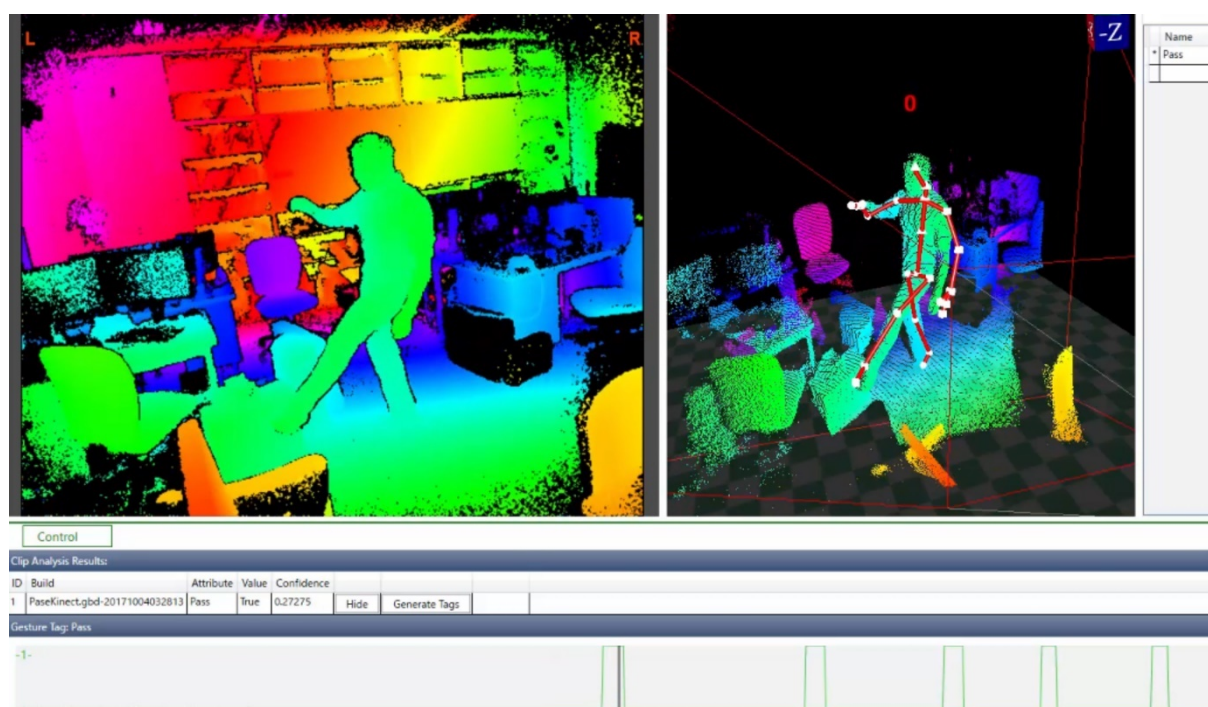


Figure 4.10. Hand-tagged video clip used for training the passing gesture recognition algorithm. The green vertical lines denote the video segments where a passing action is being performed.



Figure 4.11. Kinect feed from a player making a pass inside the VE. On the left, the player's skeletal image as perceived by Kinect. On the right, the player's PoV of the scene.



## **CHAPTER 5**

### **EXPERIMENT: VEA PERFORMANCE ACCORDING TO PLAYER SKILL LEVELS**

#### **5.1 VEA evaluation of Amateur and Beginner soccer players**

An experiment was designed to assess our system's capacity to measure the VEA of soccer players and subsequently their ability to Read-the-Game.

Our system's validation was performed with collaboration from twenty-four (24) soccer players (7 females, 17 males, ages 19–30, mean age = 22.95, SD = 3.31). Twelve (12) players were university students self-assessed as beginners without reported soccer training experience, merely playing for recreational purposes. The other twelve (12) players were from the University of Tsukuba soccer team. When writing this dissertation, the University of Tsukuba soccer club system has 198 active players divided into six teams, depending on their level and experience [100]. Their coach selected twelve players from the top university team, and these players were assessed to be "Amateur" players aiming for the professional level. All the players were either central defenders (center-back) or defensive midfielders, as the proposed VR training drill was intended for such positions.

The experiment started by reading a detailed explanation of the experimental conditions, safety risks, experimental outline, methods, necessity, and use of personal information. If the subjects agreed, they proceeded to sign a letter of consent.

All the experimental protocol was previously approved by the Ethics Committee for Human Subject Research at the University of Tsukuba, Japan.

Once the explanatory phase was over, each subject proceeded to experience the VR simulation, following the workflow explained in section 4.4.2 and the same order as shown in Fig 4.8.

The average duration of the experiment was 20 minutes. The subject stands at 1.5 meters from the Kinect sensor; then, the experimenter proceeds to help the subject colocate the HMD on his/her head while checking for correct adjustment and comfort. Once the subject confirms to be ready, the simulation starts. A volunteer experiencing the simulation with the full setup can be observed in Fig 5.1.

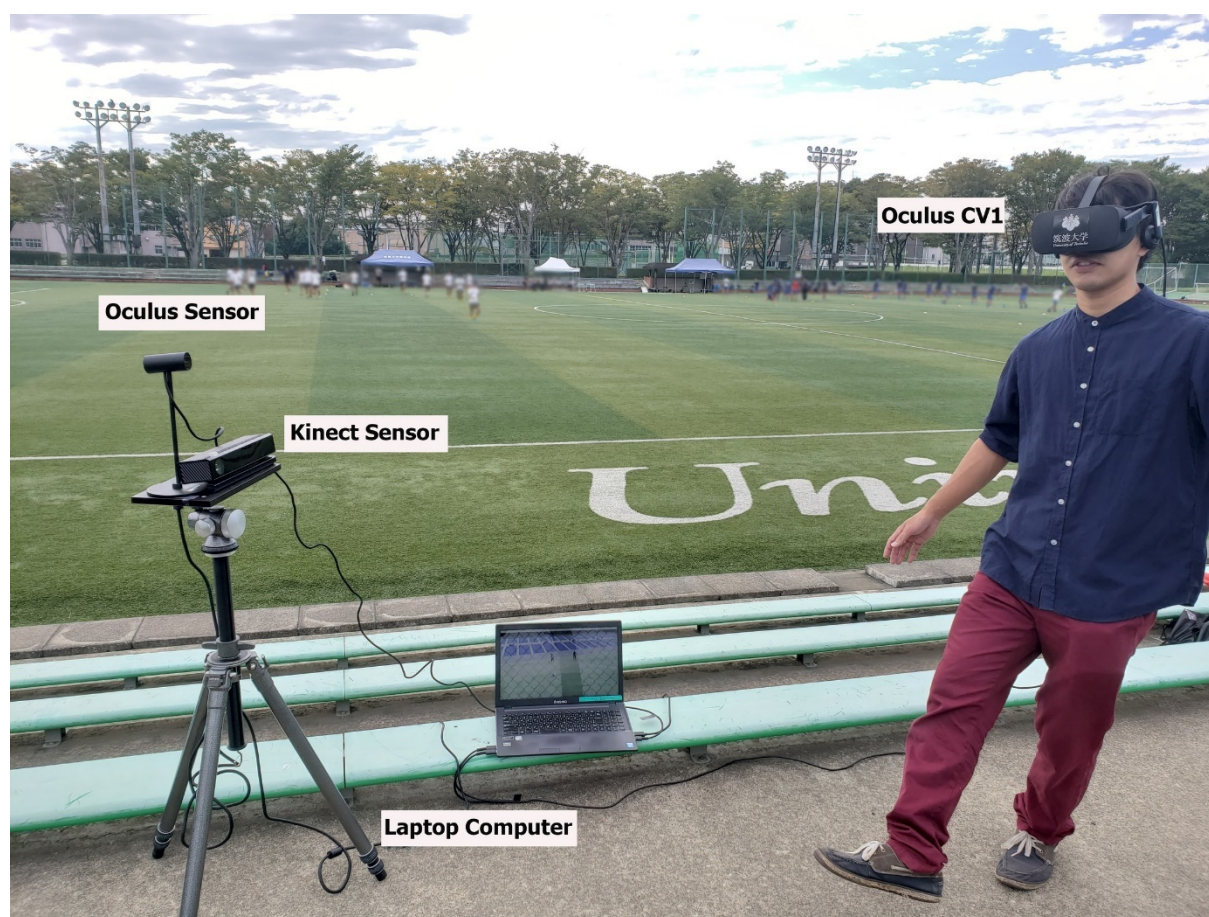


Figure 5.1. A volunteer enacts a passing gesture while he experiences the VR simulation.

Once the subject completes each tutorial scene successfully, the experimenter warns the subject that he is about to experience the intended in-game situation and is asked to act to the best of their capacity in the allotted time. Once the subject confirms to be ready, the Test scene starts, and the VEA is measured. After the player performs the pass inside the VE, the simulation ends, and the experimenter removes the HMD.

The volunteering subject then proceeds to a nearby table to answer the Japanese version of the IPQ questionnaire introduced in section 4.3 with an added free comments section, as seen in Fig 4.1.1 and Fig 4.1.2. After the IPQ questionnaire is answered, the experiment concludes.

For the sake of input comparison, another round of experiments was performed with ten (10) university players following the same protocol while utilizing the button press passing mechanic instead of the gesture-based one, as explained in section 4.5. A full detailed explanation of the Gamepad-only experimental study can be found in our published paper [101].

### **5.1.1 VEA score results and statistical analysis**

Regarding the VEA performance, the evaluation was based on the head excursion data obtained during the Test scene with the technological approach explained in section 3.3.2. The assessment criteria for determining the VEA score was applied following the method introduced in section 3.3.3. The VEA score range from 0 to 100, representing the percentage of frames the user spends looking at zones 2 and 3 before making the ball pass. Therefore, the VEA score represents both wide and 180° visual exploratory activity.

The obtained VEA scores for both beginner and amateur players can be fully appreciated in Table 5.1.

<b>Test Subject</b>	<b>Level</b>	<b>Gender</b>	<b>VEA</b>
Subject 1	Beginner	Female	22
Subject 2	Beginner	Male	20
Subject 3	Beginner	Male	3
Subject 4	Beginner	Male	48
Subject 5	Beginner	Male	46
Subject 6	Beginner	Female	53
Subject 7	Beginner	Male	37
Subject 8	Beginner	Male	49
Subject 9	Beginner	Female	0
Subject 10	Beginner	Female	25
Subject 11	Beginner	Female	39
Subject 12	Beginner	Male	28
Subject 13	Amateur	Male	58
Subject 14	Amateur	Male	41
Subject 15	Amateur	Male	29
Subject 16	Amateur	Female	50
Subject 17	Amateur	Male	50
Subject 18	Amateur	Female	51
Subject 19	Amateur	Male	74
Subject 20	Amateur	Male	73
Subject 21	Amateur	Male	25
Subject 22	Amateur	Male	15
Subject 23	Amateur	Male	54
Subject 24	Amateur	Male	78

<https://doi.org/10.1371/journal.pone.0230042.t001>

Table 5.1. This table shows each subject's VEA scores, divided by level, gender, and obtained score.

As observed in Table 5.1, amateur players showed an overall better VEA score (mean, 49.83; SD, 19.86) than beginners (mean score, 30.83; SD, 17.61). We applied an independent sample t-test statistical evaluation to explore any significant difference between players of different levels of expertise. All the statistical analysis was done with the IBM SPSS software for advanced statistical analysis [102].

The equality of variance was checked by applying Levene's test ( $p\text{-value} = 0.931$ , 95% confidence). We observe that the  $p\text{-value}$  ( $>0.05$ ) was not significant, so we then assume equality. The t-test resulted in a  $p\text{-value}$  of 0.021. By checking the value of the 95% confidence interval of the difference ( $-34.896$  to  $-3.103$ ), we can conclude a statistically significant difference between Amateur and Beginner players. Thus, we confirmed that amateur players with more experience tend to explore a wider area of their FoR while looking for passing opportunities compared to beginners. The mean score of each group can be observed in Fig 5.2.

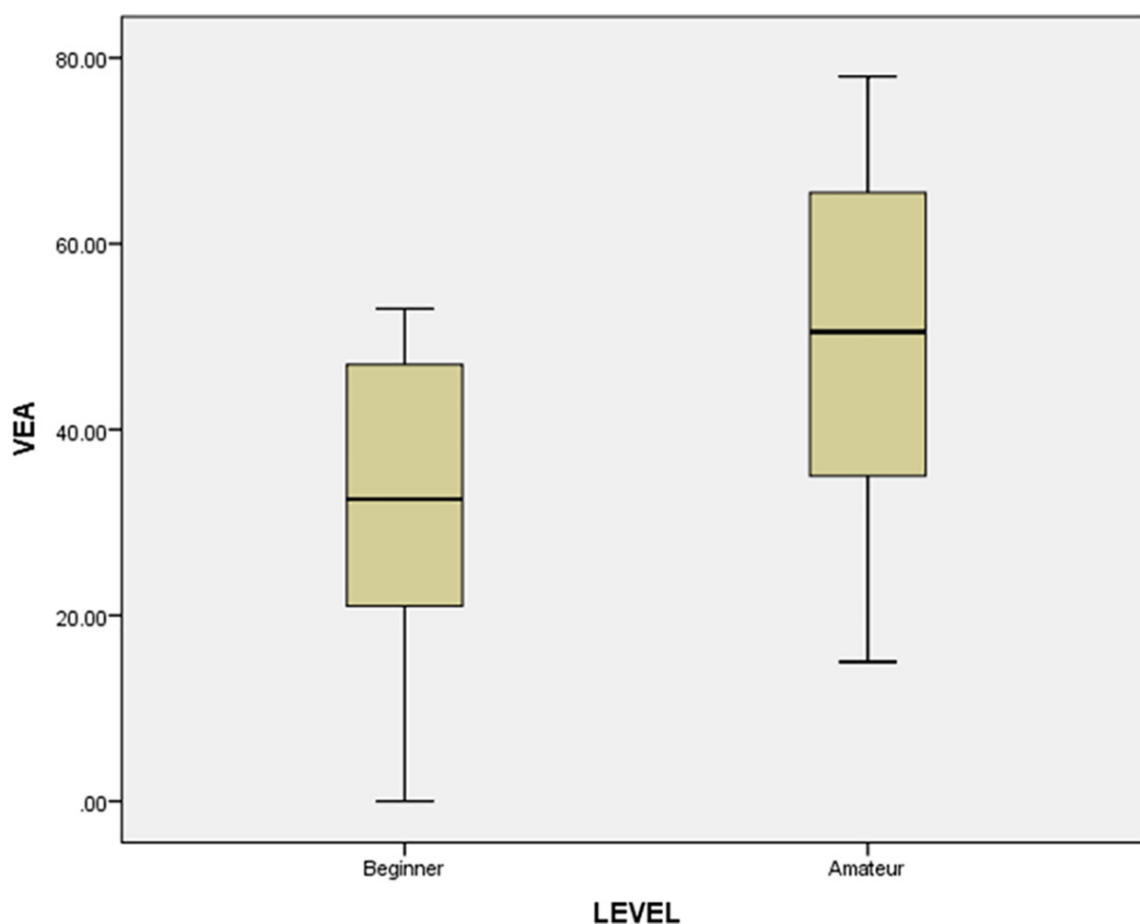


Figure 5.2. Box and whisker plot of mean VEA scores in relation to the player's level of experience (beginner vs. amateur).

### **5.1.2 Presence results and statistical analysis**

The Presence construct was measured according to the method established by the iGroup project consortium, utilizing the IPQ scale [74] [82] [103] [104] [105]. The questionnaire is composed of 14 Likert scale questions ranging from 0 to 6. The questions are grouped in three sub-scales representing Spatial Presence (SP), Involvement (INV), and Experienced Realism (REAL) with an independent scale related to the general or global sense of Presence (GP). The IPQ can be taken as a global score (GLOBAL) as the Presence construct's overall representation, with the GLOBAL cumulative score ranging between 0 to 84 [106].

The detailed explanations regarding the questionnaire scale and composition can be seen in section 4.3, and the specific applied Japanese version can be observed in Fig 4.1.1 and 4.1.2.

The obtained value in each sub-scale, general scale, and cumulative score obtained while utilizing the system's Kinect setup can be seen in Table 5.2.

Table 5.2. Presence questionnaire values obtained with the Kinect configuration of the setup, according to IPQ three sub-scales (SP, INV, REAL), one independent scale (GP), and the cumulative score representing the general Presence construct (GLOBAL).

Test Subject	GLOBAL	GP	SP	INV	REAL
Subject 1	50.00	3.00	24.00	9.00	14.00
Subject 2	41.00	3.00	17.00	12.00	9.00
Subject 3	70.00	6.00	24.00	21.00	19.00
Subject 4	43.00	5.00	17.00	12.00	9.00
Subject 5	47.00	4.00	20.00	15.00	8.00
Subject 6	55.00	5.00	25.00	18.00	7.00
Subject 7	34.00	3.00	13.00	11.00	7.00
Subject 8	45.00	5.00	20.00	14.00	6.00
Subject 9	73.00	6.00	23.00	25.00	19.00
Subject 10	53.00	5.00	23.00	15.00	10.00
Subject 11	59.00	6.00	25.00	16.00	12.00
Subject 12	61.00	5.00	22.00	18.00	16.00
Subject 13	49.00	5.00	18.00	14.00	12.00
Subject 14	44.00	4.00	20.00	12.00	8.00
Subject 15	53.00	5.00	20.00	17.00	11.00
Subject 16	68.00	6.00	24.00	21.00	17.00
Subject 17	47.00	2.00	23.00	13.00	9.00
Subject 18	51.00	5.00	21.00	11.00	14.00
Subject 19	51.00	4.00	19.00	16.00	12.00
Subject 20	41.00	4.00	16.00	11.00	10.00
Subject 21	67.00	6.00	29.00	18.00	14.00
Subject 22	68.00	5.00	25.00	22.00	16.00
Subject 23	43.00	5.00	17.00	10.00	11.00
Subject 24	48.00	5.00	18.00	17.00	8.00

GLOBAL: global score of the composite measure of the IPQ questionnaire, GP: general presence, SP: spatial presence, INV: involvement, REAL: sense of realism.

<https://doi.org/10.1371/journal.pone.0230042.t002>

The obtained values from the IPQ items were as follows:

**General Presence (GP):** This value reflects the user's subjective perception regarding the general sense of "being there" inside the VE. GP was high amongst subjects, ranging from 0 to 6 (mean, 4.67; SD, 1.09).

**Spatial Presence (SP):** Concerning the subject's perception of physically being present in the VE, the value was high. The SP values range from 0 to 30 (mean, 20.96; SD, 3.70).

**Involvement (INV):** Regarding the degree of attention given to the VE and the related subjective perception of "involvement" with the task, the value was slightly high. INV values

range from 0 to 24 (mean, 15.33; SD, 4.16). This specific value depends on the type of controller used, further explained in the following section.

**Realness (REAL):** When it comes to how realistic the VE seemed to each subject, the value was rather moderate compared to the other scales. REAL value ranges from 0-24 (mean, 11.6; SD, 3.81). The perceived realism may be particularly affected by the lack of more photorealism inside the VE.

The cumulative value of all the IPQ factors was:

**Global Score (GLOBAL):** The overall value describing the complete Presence construct perceived by the subjects was high in general. The GLOBAL value ranges from 0 to 84 (mean, 52.54; SD, 10.54), showing that the system with the Kinect configuration elicits a high sense of Presence; in other words, it is highly immersive.

### **5.1.3 Influence of input methods in Presence and VEA**

For the comparison of the effect derived from the type of input method, the obtained Presence and VEA results were contrasted with two types of controllers. The values obtained with Kinect shown in section 5.1.1 and 5.1.2 were compared with the values reported in our previous work, following the same experimental procedure with the type of controller being the only different variable [101].

Correlation tests were done between the VEA scores and Presence results for both input options:

The normal distribution of the data resulting from the experiment done with the Kinect input is checked with the Shapiro-Wilk test, done to VEA and IPQ resulting GLOBAL value (total sample, VEA p-value = 0.667 and GLOBAL IPQ p-value = 0.159). Normality was confirmed by visual inspection of the corresponding histogram.



Once the data normality was confirmed, Pearson correlation tests were done to explore which Presence construct elements were related to VEA performance. There was a strong correlation between the global composite IPQ value and the VEA score ( $r = -0.542$ ). The three sub-scales SP, INV, and REAL correlations were also statistically significant. In comparison, the general presence scale (GP) did not present a statistically significant correlation. The results of the Pearson correlation can be observed in table 5.3.

In the Gamepad configuration, there was no significant correlation between VEA score and the global construct of Presence [101]. Regarding the IPQ factors, there was no significant correlation in GP, SP, and REAL. However, in the case of INV, there was a strong negative correlation ( $r = -0.668$ ). Involvement, in particular, is affected by the degree of interactivity between the user and the VE; thus, the button press mechanic for passing the ball, which is somewhat unnatural to soccer dynamics, exerted a negative effect on the perceived sensation of task engagement. It is essential to observe that this negative correlation was absent in the Kinect, suggesting a higher level of engagement and perceived "naturalness" in the type of interaction. The results of the Pearson correlation can be observed in table 5.4.

The decision criteria for correlation intensity was based on the definition established in Cohen's seminal work [107]. All these results can be seen in full detail in our previous publication [108].

Table 5.3. Pearson correlation between IPQ results and VEA scores when using Kinect as the input option.

VEA Score Correlation	GLOBAL	GP	SP	INV	REAL
Pearson Correlation	−0.542**	−0.197	−0.452*	−0.420*	−0.547**
Sig. (2-tailed)	0.006	0.357	0.027	0.041	0.006
N	24	24	24	24	24

\*\* Correlation is significant at the 0.01 level (two-tailed)

\* Correlation is significant at the 0.05 level (two-tailed)

<https://doi.org/10.1371/journal.pone.0230042.t003>

Table 5.4. Pearson correlation between IPQ results and VEA scores when using Gamepad as the input option.

VEA Score Correlation	GLOBAL	GP	SP	INV	REAL
Pearson Correlation	−0.481	−0.106	−0.137	−0.668*	−0.434
Sig. (2-tailed)	0.159	0.771	0.706	0.035	0.210
N	10	10	10	10	10

\* Correlation is significant at the 0.05 level (two-tailed)

<https://doi.org/10.1371/journal.pone.0230042.t004>

## **CHAPTER 6**

### **DISCUSSION AND FURTHER STUDIES**

#### **6.1 Ongoing Research**

This work aimed to explore how players Read-the-Game in order to make effective in-game decisions. By identifying the perceptual-cognitive abilities that comprise the Read-the-Game skill, we established the four elements that need to be present to assess and train the skill correctly. Furthermore, by focusing on the visual elements of the Read-the-Game skill that is less explored, we were able to add new insights related to the VEA in the function of the head excursion of soccer players.

We proposed, designed, and tested a technological solution to assess the VEA performance inside a VR simulation, responding to a sensitive void in the sports science community and practitioners' needs [15]. Also, by explaining the elements required to design and build the VE, we provide a blueprint for researchers and practitioners that wish to implement a similar approach in the future.

The proposed system was tested and validated by designing an experiment in which players of different levels of expertise were required to engage in VEA to the best of their capacity before making a passing decision. The results showed a statistically significant difference between beginner and amateur players. The latter group showed a more significant area of coverage in their head excursions before making a ball pass. These findings are congruent and support previous research results that suggested a lesser visual exploratory frequency or VEA of young players than expert and more experienced ones [109].

One of the main advantages of the proposed system is the availability of the full area surrounding the user or FoR to present possible passing options. To the best of our knowledge

capacity, the only alternative technological approach available at the moment of writing this thesis did a controlled experiment with four pre-determined locations by positioning monitors in the player's FoR [110]. Albeit being a valuable contribution to the field, as a VR training solution is somewhat limited, presenting a complicated setup with non-immersive display technology [56]. The solution presented in this thesis solves these limitations by offering a self-contained setup, using off the shelf consumer-level hardware with a highly immersive VR implementation.

Moreover, the proposed system focuses on ball pass as the key game action to assess and study. Passing in soccer is deemed one of the four fundamental ball actions to train and assess a player's motor skills [111]. The full-body immersive Kinect implementation allowed the correct enactment of the ball passing motions inside the VE. The current system focus on ball pass, but with the procedure shown in section 4.5 is possible to adapt the system for recognizing shoot or dribble gestures in future iterations. We invite the ever-growing HCI community to explore further athletes' performance based on naturally mapped controller theory.

Regarding the psychological aspect of the present study, we were able to test the proposed system's capacity to elicit a high sense of Presence to the user. We considered the available controller inputs, as described in section 4.5. By utilizing kinesic natural mapping, we expected a higher sense of Presence than traditional control mechanics. Given the naturality with which the soccer-specific motor actions can be executed, the obtained IPQ results showed a higher sense of Presence with the Kinect setup. The Kinect setup allowed the players to concentrate on the task while feeling immersed in a soccer match experience, without any input effect-related interference on the VEA performance.

In contrast, the Gamepad version of the system negatively affects the player's perceived VE involvement. There was a negative correlation between the VEA and Gamepad's sense of

Presence INV sub-scale. The INV factor is influenced by the degree of attention given to the VE, affected considerably by the type of input of the system [74] [82] [103] [104] [105]. Seemingly, the button press mechanic made the players feel "detached" from the VE, focusing part of their attention on the unnatural button pressing action, not proper of the soccer context. However, we did not test our system with other input implementations. In future work, other controller options should be explored.

The real-world skill transfer potential of the proposed system has not been tested. To further validate the VR solution as a training tool, it is necessary to perform complementary experiments focusing on real-world performance effects. A tentative procedure is suggested in related work that shows the impact of imagery intervention in real-world VEA performance [34].

Another limitation to consider is the relatively limited sample size. Therefore, it is necessary to perform future experiments that challenge the presented results with different player levels.

Other in-game situations should be further tested to compare the VEA of players in different positions and situations. The present work sets the methodology and system guidelines for developing a myriad of future research works that may further explain how soccer players explore their surroundings, focusing on their head excursion within a self-contained VR solution.

This dissertation's main body focused on one of the key visual elements of the Read-the-Game skill as previously defined in Chapter 3. In the following sub-sections, we will introduce further developments of the proposed VR simulation, followed by an alternative application of the VEA measurement method proposed in section 3.3.2.

## **6.2 Further investigation with EEG**

As defined in Chapter 3, the Read-the-Game skill comprises four major sub-elements, two cognitive and two visual. In this thesis's main body, we introduced a system that focuses on the least explored visual aspect of the skill. In this section, we will briefly introduce the latest developments related to the VR system.

To verify soccer players' cognitive state concerning their VEA behavior, we propose implementing a novel Electroencephalography (EEG) headset designed explicitly for VR HMD's [112].

Previous research suggests that higher alpha power activity is linked to creativity in soccer players in relation to their brainwave patterns [113]. The proposed setup provides brainwave data about alpha, beta, gamma, theta, and delta power per 100 ms, with composite attention, relaxation, and brain balance indexes accessible in real-time [114]. We adapted the headset to our VR system, intending to obtain the attention index of soccer players while engaging in VEA. The attention index provided by the EEG headset is obtained by calculating the average and standard deviation of the beta/alpha wave.

Regarding motion tracking, we already had good results by using Kinect as the tracking device. To compare our solution's tracking performance, we switched to a MoCap implementation, pursuing continuous system performance improvement.

Finally, to complement the VEA behavior profiling, we added eye-tracking technology with the HTC VIVE Pro Eye. Unlike the Oculus CV1, the Pro Eye model comes with Tobii eye trackers, offering the possibility to assess gaze attention by measuring eye fixation duration and position [115]. A recent study using Tobii eye trackers in real game situations suggests that players tend to fixate on four elements: ball, spaces, teammates, and rivals [37]. We build on

their method to further clarify the visual exploratory patterns and objects of interest under controlled experimental conditions thanks to our VR approach.

With the newer system, we can obtain head excursion, eye fixations, and cognitive attention. Therefore, we can advance in establishing the needed cognitive and visual skills required to Read-the-Game appropriately.

This work is under development, and the paper introducing the EEG approach described above is accepted for publication at the moment of writing this thesis [116].

The setup diagram of the newer version of the system can be observed in Fig 6.1.

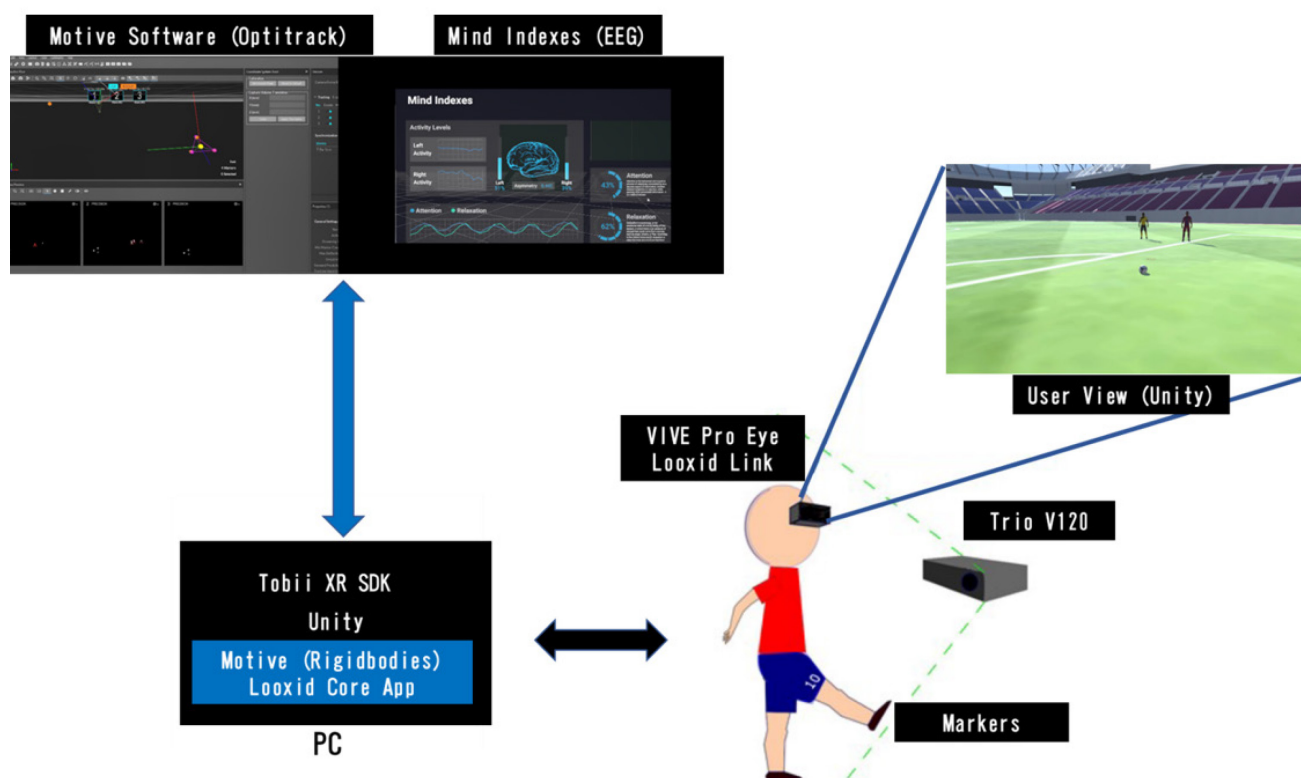


Figure 6.1. Diagram: newer system version, including eye-tracking and EEG.

### **6.3 A case study of VEA in a Microgravity environment**

The method for measuring the VEA performance in function of the user head excursion with an HMD, previously introduced in section 3.3.2, could be applied in a non-sport context. This side project aimed to test our method's transferability to other fields interested in VEA research.

This side project was part of a unique course of the doctoral program's curriculum to which the author is affiliated, the Ph.D. Program in Empowerment Informatics at the University of Tsukuba. In this course, the students propose experiments, performed in a parabolic flight, sponsored by the program and with supervision from The Japan Aerospace Exploration Agency (JAXA).

The experiment aimed to explore how humans visually explore their surroundings in microgravity conditions. While experiencing weightlessness, the human body cannot rely on static visual cues for orienting themselves as they do on earth, difficulting the perception of upright (PU) as a consequence [117]. Thus, the human body undergoes a severe process of adaptation while relying mainly on its visual function. Besides vision, microgravity severely affects the afferentation from the vestibular, tactile proprioceptive, and support system, resulting in the disturbance of visual tracking capabilities [118]. Hence, it is crucial for astronauts and those who train them to understand in detail how their VEA can be affected during a mission; more so, if we consider the hazards they are exposed to during spaceflight.

We obtained the yaw, pitch, and roll motions from the HMD during a spacewalk simulation performed in the VE under microgravity conditions. The subject was required to visually search and locate a CG model of the International Space Station (ISS) located randomly in his FoR, in any axis. This exercise was performed repeatedly as many times as the flight duration allowed; two runs were done with the subject sitting with his seatbelt on, and two runs



while freely floating in the free space available inside the aircraft. The experiment was repeated on earth (one-G) for the sake of comparison. The subject responded to the IPQ questionnaire and gave his observations in a free comment section. The image of the subject in both conditions can be appreciated in Fig 6.2, and the experimental workflow during one parabolic segment can be seen in Fig 6.3.

The results demonstrated a statistical difference regarding roll movement in microgravity compared with one-G (p-value= 0.04, 95% confidence) within the free movement postural condition. The subject relied more on roll movement in microgravity to use the motion's inertia to navigate better and position himself. In the presence of gravity, humans tend to avoid tilting their heads with roll motion while engaged in VEA at a constant velocity. This type of motion alters the semicircular canals closely related to the roll axis, resulting in nausea and motion sickness [119]. However, in weightlessness, this condition changes, and the body feels relatively more comfortable, tending to engage more in roll movement as a consequence.

There was no significant difference in the yaw and pitch axis.

The subject showed to experience a more substantial Presence in one-G condition. We hypothesize that the less amount of perceptual distractors in a familiar environment may help the subject to engage better with the VE task, unlike microgravity, where the subject was constantly aware of his navigation and hazards of floating around the plane. Nevertheless, it is important to mention that these results are merely inferential, given the limited sample size.

Finally, the subject interestingly expressed to feel less motion sickness when using VR during microgravity conditions. The subject had previous experience with parabolic flights, in which he felt heavy Space Motion Sickness (SMS) symptoms after each flight without using an HMD. We hypothesize that this may be the product of the visual flow provided by the VE. The simulation portrayed outer space, without any clear roof or floor visual reference. Therefore,

the mismatch between the visual flow and the vestibular system was less intense. Without an HMD, the user is continuously looking at the plane's inside with clear visual PU without adequate otolith stimulation [120]. These visuo-vestibular incongruence has been associated with motion sickness symptoms [121].

We consider it especially appealing to explore the potential of VR as an SMS countermeasure, considering the real danger it signifies for astronauts in critical missions [122]. VR tends to be related to motion sickness on earth, so exploring the technology potential to do the contrary outside of our planet is fascinating and worth pursuing.

The extended findings of this work can be found in our published paper [123].



Figure 6.2. Left: The subject is performing the VEA task in the "free space" inside the aircraft. Right: The subject performs the task in the sitting area. Right: The subject is performing the VEA task while sitting in the aircraft.

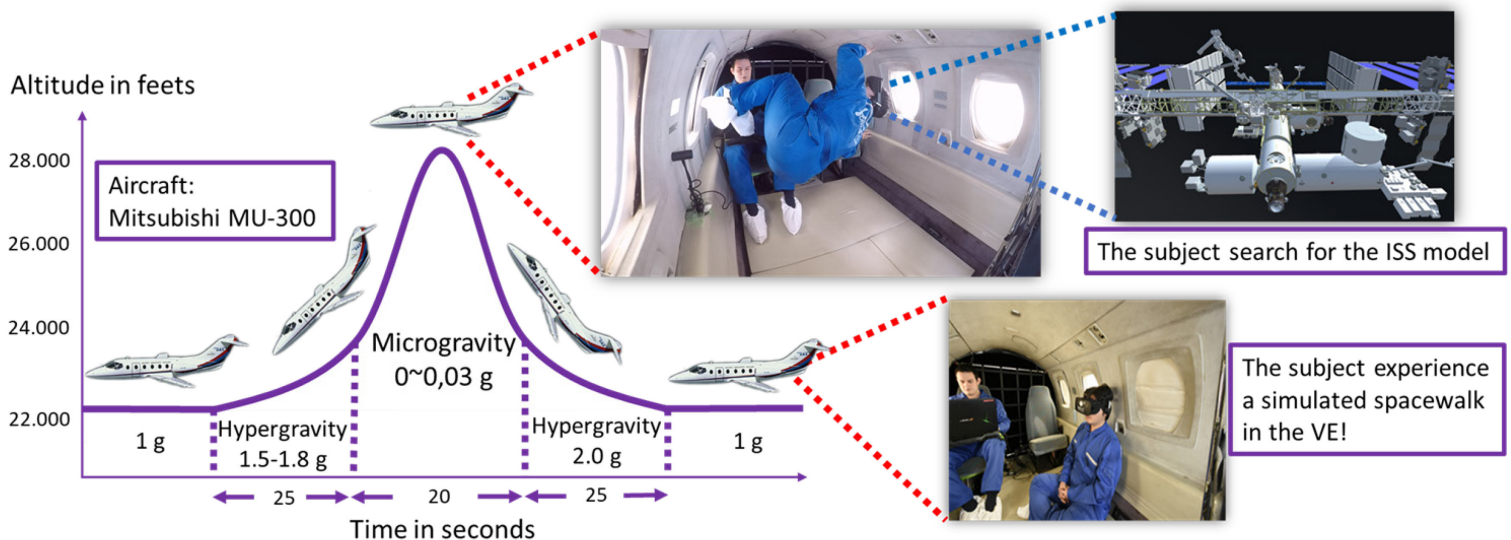


Figure 6.3. Experimental workflow during the parabolic flight.

## CHAPTER 7

### CONCLUSIONS

In this thesis, we wanted to clarify where soccer players look at before making in-game passing decisions; in other words, how do they Read-the-Game? Concretely, we started this work with the question: **Can we assess the player's Visual Exploratory Activity (VEA) performance with full-body immersive VR?**

We got a positive answer, proving that it is possible to correctly measure VEA activity difference related to the player's level of experience inside an immersive VE. We proposed a novel approach of measuring the player's head excursion with an HMD in VR while the player engages in VEA under a real life-like in-game pressure situation. Furthermore, we successfully implemented full-body interaction with the VE, offering a new vista for the HCI research community by providing insights into how full-body immersive VR can benefit soccer-specific VEA coaching solutions.

In this work, we provide an operational definition of the Read-the-Game skill for the first time by identifying four key elements. Thus, we pave the way for future researchers in the sports science, engineering, and sport psychology fields to further advance the study of the Read-the-Game concept with a concrete, reproducible methodological background. By evaluating players of different levels of expertise, we found that those with more experience tend to visually explore a broader area before making a passing decision, engaging more actively in head and body pivot rotations. The proposed system allowed the players to execute ball passing actions, engaging in full realistic motion with kinetic motion tracking. Moreover, we proved the effectiveness of full-body immersive interaction to elicit a higher sense of Presence over standard gamepad inputs. As a result, the Kinect version of the system facilitates

a smooth VEA performance in VR, an essential element to assess the Read-the-Game skill concept. The proposed setup is easy to reproduce and may serve as a testbed for future applications in this promising field of research, using sports science, human-computer interaction, and psychology concepts in perfect synergy.

In Chapter 1, we explained the motivation for pursuing the topic at hand. Then, we posed the research question that kickstarted the presented research endeavors, followed by the contribution and thesis structure.

Chapter 2 introduced the related works, establishing the importance of clarifying the underlying components of soccer players' in-game decision-making process from a sports science perspective. We established the necessity of our approach based on existing literature.

Later, by establishing the need and operational definition of the Read-the-Game skill in Chapter 3, we were able to identify the least explored visual element of the skill. That is, the player's VEA performance is highly based on the head excursion. Next, we explained the importance of full-body interaction for creating immersive sport VR experiences. Then, we showed our method for measuring the player's head rotation with an HMD inside a VR simulation. Furthermore, we defined the core referential areas (zones) used for assessing VEA performance.

For Chapter 4, we introduced existing VR applications in sports training and assessment. We also clarified the importance of measuring psychological byproduct Presence in VR applications and explained the method for its assessment based on psychometric questionnaires, which questionnaire we applied and why. Next, the VE content construction and composition were explained in detail, considering the scale and sound elements. Also, we showed the playing drill used for our simulation, ending the chapter with the construction of the full-body interaction tracking system based on Kinect and cemented in HCI principles.

Chapter 5 is dedicated to the experiment done to measure the VEA of players with different skill levels. The results and statistical analysis were presented, finding a higher VEA in more skilled players. We also found that the controller option impacted the VEA, with Kinect delivering a good experience, while the Gamepad setup negatively affected the VEA performance. These findings served to demonstrate that our proposed system can assess VEA effectively with full-body immersive VR.

In Chapter 6, we further discussed the implications and limitations of the obtained results. Followed by the introduction of the new setup of the system, with which we aim to further expand the study of the Read-the-Game construct by adding eye fixation and EEG as cognitive elements to the mix. Finally, an alternative application of the presented method for measuring VEA was shown. This example serves as a showcase of the potential of our approach for measuring human VEA within a self-contained VR simulation in various fields.

We believe that this work provides new insights for the sports community, not only about the Read-the-Game skill complex composition and study but also about the untapped potential of utilizing VR as a valuable ally in the pursuit of top visuo-cognitive performance.

The author continually strives for a VR-empowered future, where coaches and players of all levels can efficiently develop the ability to Read-the-Game, anytime, anywhere.

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# PUBLICATIONS

## Reference Papers

**The essential part of this Thesis has been published as (1), (2), (3) and (4).**

- (1) C. D. Rojas Ferrer, H. Shishido, I. Kitahara and Y. Kameda, "Read-the-game: System for skill-based visual exploratory activity assessment with a full body virtual reality soccer simulation." PloS one 15.3 (2020): e0230042.
- (2) C. D. Rojas Ferrer, H. Shishido, I. Kitahara and Y. Kameda, "Realization of a Full-body Immersive VR System for READ-THE-GAME Skill Development," The 2nd Asia-Pacific Workshop on Mixed and Augmented Reality (APMAR) 2018, Taipei, Taiwan, 2018.
- (3) C. D. Rojas Ferrer, I. Kitahara and Y. Kameda, "Read-the-game skill evaluation by analyzing head orientation in immersive VR," 2017 3DTV Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON), Copenhagen, Denmark, 2017, pp. 1-4. doi: 10.1109/3DTV.2017.8280415.
- (4) C. D. Rojas Ferrer, H. Shishido, I. Kitahara and Y. Kameda, "Visual Exploratory Activity under Microgravity Conditions in VR: An Exploratory Study during a Parabolic Flight," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 2019, pp. 1136-1137, doi:10.1109/VR.2019.8798253.

**The essential part of this Thesis is already published in the papers listed in the “Reference Papers”, and is also being contributed as the paper below (Accepted for Publication).**

- (1) Y. Kameda, C. D. Rojas Ferrer, S. Ohnishi and H. Shishido “A New Verification Approach for Subjective Evaluation of Actions in HMD-VR with EEG,” International Workshop on Advanced Imaging Technologies 2021 (IWAIT 2021).

## Other publications (Domestic conference, published as received)

- (1) C. D. Rojas Ferrer, I. Kitahara and Y. Kameda, "Training soccer players' ability to READ-THE-GAME in full-body immersive VR," ITE Technical Group on Sport Information Processing (SIP), 2018. 2018/02/13, University of Tsukuba, Japan. ISSN 2424-1970
- (2) C. D. Rojas Ferrer, I. Kitahara and Y. Kameda, “A Prospective Study About Enhancing Effect of VR in Soccer Training”, IEICE Technical Report, MVE, vol.116, no.150, pp.25-30, 2016. 2016/7/20, The University of Tokyo, Japan. ISSN 2432-6380
- (3) C. D. Rojas Ferrer, I. Kitahara, Y. Kameda and Y. Ohta, “Players Displacement Based on Captured Data in a VR Soccer Training Simulation” Proceedings of the 2015 IEICE General Conference, pp.306, 2016. 2016/3/15-18, Kyushu University, Japan. ISSN 1349-1377.

