Ability evaluation of basketball players on responding to situations in VR simulator*

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Abstract

A basketball player's ability to respond to situations is an important factor that greatly influences the outcome of a game. In this study, we propose a method to evaluate the situational ability of basketball players using a VR simulator. The VR simulator replicates a 2-on-2 game scenario, and the system captures the players' line of sight and movements. The Head-Mounted Display (HMD) records the gaze, while the movement is tracked by capturing images of the player and estimating the player's skeletal structure using OpenPose. We then propose and analyze an index, derived from the collected data, that represents the player's situational responsiveness. From the collected data, we propose and analyze indicators of situational responsiveness. The indicators include gazing objects, number of head turns, body movement, movement trend, and average reaction time. In the experiment, we showed that the proposed indexes can be used to objectively evaluate the players' ability to respond to situations by analyzing them. This study was conducted to evaluate the complexity of a basketball player using a VR simulator. This research introduces and validates an innovative method for evaluating basketball players' ability to respond to complex situations using a VR simulator. We believe that this research has the potential to make a significant contribution to the field of sports analysis.

Keywords

skeletal estimation, posture estimation, eye tracking, head-mounted display, basketball, virtual reality, situational awareness, sports science, sports engineering

1. Introduction

Basketball players need to adapt to many changes in a short period in the complex situations they face[1]. Players need to be able to adapt their actions to the situation. We call this ability situational adaptability. During a game, it is important to know what the players are looking at, what they should do, how they should analyze, and what they should do. What the players should do during the game should be analyzed to clarify their situational ability. This will contribute to the development of sports if we can evaluate and understand their situational skills. However, at present, there is no established method to evaluate players' ability to respond to situations properly. However, at present, there is no established method to evaluate players' ability to respond to situations properly.

Since a situation-based ability evaluation method is required, a system that can evaluate actions during a game is needed. A VR simulator that can control the situation is suitable to enable players to experience the situation during a game. In this system, players' actions should be recorded in detail so that the players' ability to respond to situations during a game can be evaluated objectively. The actions can be recorded in terms of eye movement and body movement. We consider recording these two types of information in the system. In previous studies [2] [3], gaze information was quantitatively recorded. The analysis that combines eye gaze information and body motion should be conducted further. Gaze can be expressed as a vector in spatio-temporal space. Body movements can be quantified by skeletal representations using recent skeletal estimation methods. By combining these two types of quantified information, we can develop a system and index that can be used to evaluate players' abilities.

In this study, we propose a new method for evaluating players' ability to respond to situations. A VR simulator that can reproduce a realistic game situation is constructed so that basketball players can make decisions and take actions based on the same experience as in a game. Based on the information obtained, we propose an index that is useful for evaluating the basketball player's ability to cope with complex situations [1].

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Although the ideal scenario would be to prepare an experience equivalent to an actual game, in order to simplify the factors to be considered when devising the indicators, we decided to adopt a two-on-two scenario after discussions with the coach and the manager of the University of Tsukuba basketball team.

The eye movement of the players is measured using the position and posture measurement function of the head-mounted display used for the VR simulator and its internal eye-tracking function. The body movements of the players are recorded by an external camera and analyzed later; skeletal information is estimated by OpenPose[4], and three-dimensional information is obtained from the constraint condition of the positional relationship between the camera and the players. The players' eye movement and body movements during the scenario experience are evaluated based on the proposed index.

2. Related research

As research that uses data to analyze players not only in situations in sports but also in football and baseball as well as basketball, George et al.[5] analyzed the changes in players' expressions over time and their tendencies to choose offensive routes. This shows the importance of data in objectively evaluating players.

Hughes et al.[6] examined the use of indicators in analyzing player performance in their research. They showed that general match indicators can be classified into tactical, technical, and biomechanical indicators. They also point out that the comparison of data is essential to allow a complete and objective interpretation of the data from the performance analysis. We believe that it is necessary not only to create indicators for athletes in many directions but also to compare data from different athletes.

There have been reports of VR simulators for table tennis training[7] and for learning basketball[8]. The system they developed in their research allows the user to experience a game in real-time and master the skills. They evaluate the effectiveness of the training by reproducing heartbeats and the player's game situation and help the player understand the tactics of the game. These two research projects are in the field of physical education and may be applied to other fields, such as medical health care and education.

3. Indicators used to evaluate basketball players' abilities

This chapter describes the indices used in this research to evaluate the situational competence of basketball players. The data to be obtained are described first. The data to be obtained are two types of data: gaze information and body movement information, respectively. For the gaze information, the player's gaze vector, the object that collided with the gaze vector for the first time, and the direction of the player's face are recorded. In addition, the player's joint coordinates are obtained by skeletal estimation using OpenPose on the body video recorded by an external camera. Based on the above information, we propose indicators and evaluate the players.

3.1. Indicators using eye gaze information

Analyze information acquired by players during a game to analyze the motives and reasons for their actions[11]. We integrate items that can be analyzed using gaze vectors and summarize them into "gazing objects". This information, i.e., what the players look at and when they look at it, has a great influence on their behavior as a basis for making decisions. Therefore, it is assumed that the more accurate information can be collected in real-time, the better the ability to react to the situation. It has been reported that soccer players differ greatly in their ability to respond to situations depending on their position[9]. The same could be true for basketball. If the way in which people collect information differs from person to person, we can more objectively evaluate a player's ability to collect information and his tendency to select targets of attention by examining what and how much he looks at, how much attention he pays to other correlated persons, and how often he switches the targets of his attention. Therefore, not only focusing on the physical ability of players, but also evaluating their tendency to collect information and to act on it as one of the indices will provide a means of analyzing them more accurately. For this purpose, the time spent gazing at an object, the frequency and speed of looking at other people and objects are investigated by recording the players' eye vectors, and used as indicators.

The HMD also records the player's face orientation, which is used in the "head turn frequency" metric. In this metric, the player counts the number of times he turns his head to look at the other player on offense in a given period. In one of the scenarios, the player's field of view is restricted, and one of the two offensive players is outside the field of view. This method allows us to evaluate the players' defensive awareness of their own marks and their ability to make tactical decisions.

3.2. Indicators using body information

The analysis and evaluation of human movement is a growing area of research in the field of sports monitoring. This analysis helps athletes improve performance, predict injuries, and optimize training programs[10]. We use

no review with the same authors in [19].

OpenPose to estimate the skeleton from images recorded by an external camera in order to analyze the motion. The joint coordinates are obtained from the estimation, and the distance between the camera and the player can be calculated using the epipolar constraint method. Thus, it is possible to calculate the distance between each joint of the player in a plane parallel to the camera's image plane. Details of the use of the epipolar constraint method and the calculation of the distances between joints are described in Chapter 5. In addition, visualization of the distances between joints with respect to time and visualization of the rate of change of the distances between joints with respect to time are provided. With these two items, it is possible to evaluate "body movement" and "intensity of movement." Body movement allows us to evaluate when and how much a player raises his hands, whether he has sufficient defensive intention against an opponent's action, and whether he makes a quick decision against an opponent's feint. The intensity of body movement can also be analyzed in terms of a player's instantaneous power, fitness management, tactical tendencies, and tendency to close off all possible penetration routes, or to focus on key points with good timing.

The head positions of players are recorded by the HMD, and by visualizing the data, the "movement tendencies" of the players can be evaluated. Since the position of the players in a game has a great influence on tactical decisions and the situation of the game, it is necessary to analyze the movement tendencies of the players for each situation. The movement trajectories of the players with respect to time make it possible to analyze the tendency of players to move forward to help or to back up and defend their own marks in response to a known scenario. The recording of the movement trajectories of the players in the different scenarios also allows the evaluation of how the players handle each situation and how proactive they are in their tactical decisions.

3.3. Indicators using gaze and body information

The index "average situation analysis time" refers to the average time it takes an athlete from the moment he or she sees a situation to the moment he or she gathers information, thinks and analyzes, and starts to move. It has been pointed out that neuroreflex training has a significant impact on the acquisition of skills in sports[12]. If we actually record players' reactions to many situations, we will be able to evaluate a certain degree of representation in sports. Specifically, since players need to make decisions in a short time to defend against an opponent's actions or initiate an appropriate move in response to a complex situation, players would need to collect information on different situations and evaluate their processing speed. By limiting the situations, it is possible to evaluate the speed of information processing and the time it takes to respond to complex situations by comparing the data of each player. If the situation is relatively easy to judge, such as an opponent's pass, this indicator corresponds to the reaction time of the players. By comparing with the reaction time, we can evaluate the time required for the player to understand a complex situation.

4. VR Simulator

4.1. Hardware

Information on the HMD used in this research is described below. A head-mounted display (HMD) called VIVE PRO EYE will be released by HTC in 2019. It has a high image quality and a viewing angle of 110 degrees and can present a clear first-person view with a 360-degree perspective. With a total of 2880 horizontal pixels and 1600 vertical pixels, users can experience an image with a screen resolution of 1440 x 1600 viewed through one eye. The built-in gyro sensor and BASE STATION2 provide head tracking, while VIVE PRO EYE features eye tracking through eye rotation.

A Go Pro Hero 5 external camera is used to capture the players' movements. The horizontal, vertical, and diagonal degrees of the Field of View (FOV) were 69.5 degrees, 118.2 degrees, and 133.6 degrees, respectively.

4.2. Software

Unity, a development environment provided by Unity Technology, is used to create the 3D virtual space. Steam VR is used for this research to project the scenario on the HMD and to realize real-time monitoring during the experiment.

An indoor basketball court is constructed in a 3D virtual space to simulate a game. Figure 1 shows an overall view of the basketball court, and Figure 2 shows a bird's-eye view. Figure 3 shows a view of the goal ring from the center of the gymnasium, and Figure 4 shows a view of the goal ring from the side. The area of the basketball court is the same as the official competition court, $28meters \times 15meters$. The court is measured from the inside and all lines are $50mm$ wide. The height of the goal ring is set to the official height of $305cm$.

The NPCs used in the scenario are shown in Figure 5. Figure 6 shows the image of the offensive team as seen by the experimental participant during the game.

The components of a game are minimized so that the basketball players can concentrate during the game. Therefore, the game is reproduced in a 2 vs. 2 scenario that can reproduce multiple situations. The player who experiences the game sees the recreated game scenario from the perspective of one of the defenders.

Figure 1: Overall picture of the basketball court.

Figure 2: Basketball field overhead view.

Figure 3: Basketball court front view.

4.3. Items to be prepared in the simulator

By setting up the behavior of the 3DCG objects in advance, it is possible to reproduce the flow of a match. The system is set up in such a way that the players can watch the game situation in the first person while we can see the situation as the players see it in real-time. In order for the players to have a match experience that is close to reality, and for their cognition and actions to be as realistic as they actually are, we believe that the immersion of the experience in the scenario we have prepared is necessary. The space should be secured so that players can move at their own discretion and can move their arms and legs

Figure 4: Basketball court side view.

Figure 5: A basketball player and the ball.

while watching the game.

5. Data collection of basketball players' body and eye search using VR simulation

5.1. Gaze Information

VIVE PRO EYE, the HMD used in this research, uses eye rotation information to estimate gaze. The built-in gyro sensor and two BASE STATION2s are used to track the head. Figure 7 shows the line of sight of an athlete in the virtual space, indicated by a red line. The white and green lines representing the players' visual

Figure 6: A basketball player at the offensive pose.

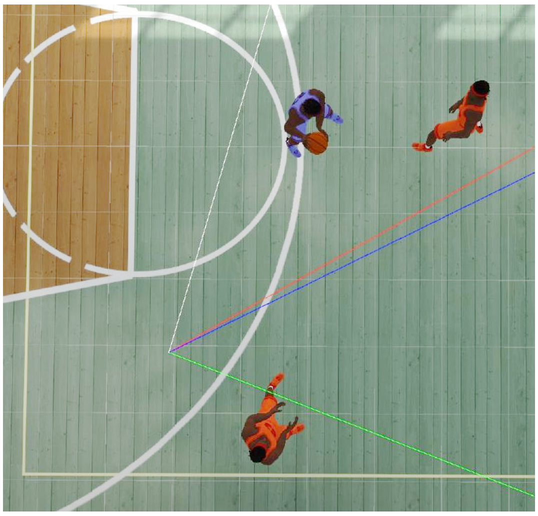


Figure 7: Image diagram of line of sight vector, visual field range, and face orientation vector.

field range have an angle of 110 degrees. The blue line in the middle represents the player's face orientation vector. Figure 8 shows an image of the game from a first-person perspective with the players wearing HMD.

A collision detection attribute is added to all objects in the virtual space, and the collision with the line-of-sight vector is used as the criterion for determining the object to be gazed at. The collision coordinates are recorded and called the gazing point. With the above data, it is possible to reproduce the motion of the player's head during his/her experience. When reproducing the player's experience, a sphere is rendered at the gazing point. When the player's gazing vector collides with the basketball, a pink sphere is rendered, otherwise, a blue sphere is rendered. An image of the collision rendering is shown in Figure 9.

Figure 8: first person view of experiment participant.

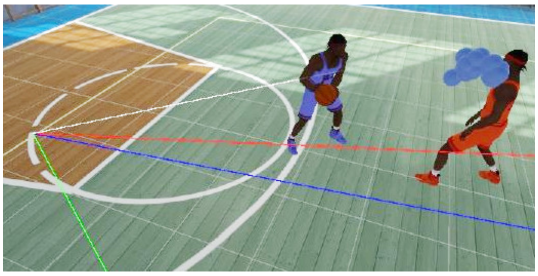


Figure 9: Collision rendering.

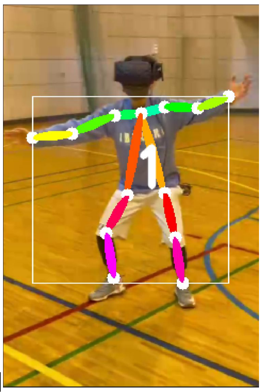
5.2. Body information

Players experience the scenario, and their defensive moves against the opponent's actions are captured by an external camera. Since the experiment participants put on HMD, the original OpenPose sometimes fails to find the head part. We have trained the original OpenPose model additionally to find the head wearing the HMD. We see that our refined OpenPose model can estimate the head wearing an HMD after the training in Figure 10.

In this research, since the head can be accurately measured by the HMD system, the position and posture information of the head can be used to represent the OpenPose posture estimation results in three-dimensional space. The position and posture of the external camera are measured in advance.

Since the players may change their body orientation during the scenario, the location of the external camera is determined in advance according to the play scenario so that posture estimation is possible in any orientation. In addition, when the player extends his hand to the offensive side of the field, the scenario design will take into consideration that the hand should be extended to the left or right as seen from the external camera.

Under the above conditions, the epipolar constraint for the player's head is shown by the red dotted line in



[before training]
[after training]

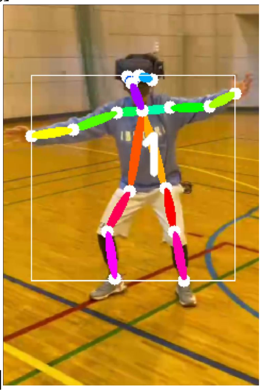


Figure 10: Refined body estimation[19].

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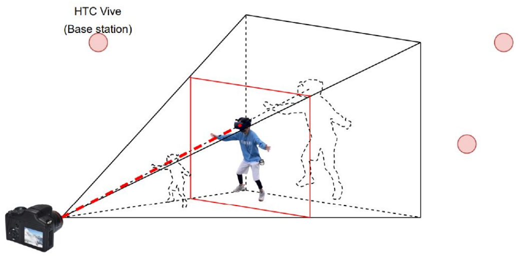

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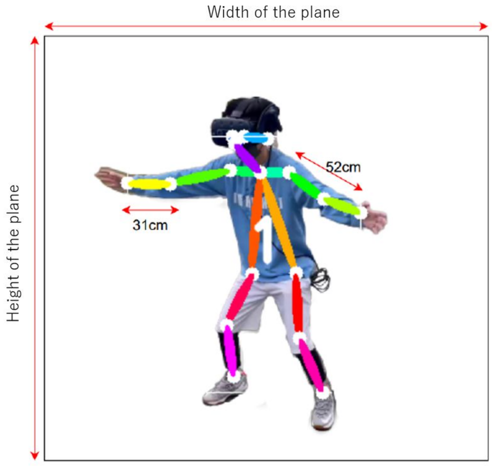

Figure 11: Expriment participant's spatial coordinates obtained under the epipolar constraint[19].

Figure 11(a).

Since the head position is recorded by the HMD and the position information of the external camera is pre-measured, the distance between the camera and the plane perpendicular to the camera optical axis can be calculated from the distance between the head and the camera. Therefore, the horizontal and vertical lengths of the image plane captured by the camera can be calculated from the FOV of the camera at the position of the subject. As shown in Figure 11(b), based on the above information, the distance between joints can be calculated using the joint information from the OpenPose estimation results, making it possible to evaluate the participant's limb movements.

The skeletal information and inter-articular distance in the plane perpendicular to the camera optical axis can now be measured spatially.

6. Experimental Structure

6.1. Reasons for determining the scenario

The scenario used in this research was created considering the following factors.

A monocular camera is used to record the movement of the person to be experienced and collect skeletal information. To obtain the most effective estimation results, the scenario should be determined by filming from the front and taking into account the effect on the orientation of the experiment participants. Factors that influence the experiment participants's judgment are minimized so that the experiment participants's ability to judge the situation can be correctly ascertained while maximizing the reproduction of the in-game situation[13], which is reported to be likely to be beneficial for decision making in a sports environment with high levels of interference and sufficient self-control. Therefore, the scenario used in this research simulates a two-on-two match.

In order for the experiment participants to experience a realistic match and to be able to make decisions that are closer to reality, it is considered necessary to make the experience of the scenario more immersive. For this reason, the movements of the NPCs in the scenario are animated using actual motion-captured movements, and the basketball court uses assets that resemble a Japanese school basketball court.

6.2. Composition of the situation

We carefully designed five scenarios in total in the game form of 2 vs. 2. The experiment participant is a member of the blue team at defense, and the two red team members attack. The three players are NPCs. The NPC that the experiment participant should deal with is called Red 2, and the other player on the Red team is called Red 1. The NPC on the Blue team who plays a defensive role against Red 1 is called Blue 1. Red 1 and Blue 1 first stand near the center of the basketball court, near the three point line. The player who experienced the game and Red 2 stand in the center of the basketball field, near the three-point line on the left side facing the goal ring. An image is shown in Figure 7. The game in all scenarios starts when Red 1 passes the ball to Blue 1 and Blue 1 throws the ball back to Red 1. The following sections describe the contents of each scenario.

Scenario 1 is created to evaluate the players' tendency to gather information. After the game starts, Red 1 dribbles and then shoots. Red 2 is within the view range of the observer. In this scenario, the player pays attention to Red 1, looks between Red 1 and Red 2 and pays attention to both, or pays attention mainly to Red 2, and so on.

Scenario 2 is to be designed so that the reaction time of the players can be evaluated. After the game starts, Red 1 dribbles and then passes the ball to Red 2, who shoots. The time from the moment the player sees Red 1 pass the ball to the moment he starts a defensive move is used to evaluate the reaction time of the player.

In Scenario 3, the setting of the situation is considered so that the players can evaluate the response to the situation when there are members of the opposing team outside of their field of vision. After the game starts, Red 1 dribbles and passes the ball to Red 2, who shoots. However, Red 2 is outside the viewer's field of vision. In this situation, if the experiment participants do not pay attention to Red 2, he/she will be hindered in judging the situation, and thus the balance of attention to the two players on the Red team can be observed.

Scenario 4 evaluates the movement tendencies of the players and their ability to judge the situation in response to an opponent's feint. After the game starts, Red 1 dribbles and feints to pass the ball to Red 2. Red 1 then briefly changes direction and dribbles to the right of the goal ring. Blue 1 chases after Red 1 and Red 2 goes for help. Finally, Red 1 shoots. The video allows the player to evaluate the presence or absence of defensive action in response to a feint pass, and the time required to determine that it is a feint can also be analyzed. The tendency to go for help can also be evaluated by the movement of the player.

Scenario 5 evaluates the tendency of players to move and their ability to judge the situation in response to an opponent's feint. After the game starts, Red 1 dribbles and feints to pass the ball to Red 2. Red 1 then briefly changes direction and dribbles to the right of the goal ring. Red 2 simultaneously crosses the three-point line in the opposite direction and approaches the goal ring. After dribbling, Red 1 feints a shot and passes the pole to Red 2. Red 2 receives the ball and shoots. In this scenario, there are two feints, and the player's reaction to them can be examined. The tactical decisions of the players can also be investigated in response to the actions of Red 2.

6.3. Acquisition of eye gaze information by VIVE EYE

In order to analyze the eye movements of players as they respond to complex situations, we describe a method for estimating their field of view and point of gaze. Based on the face direction vector from the head rotation information, the athlete's visual field boundary is a line with a 55-degree left-right opening. As shown in Figure 1, the player's visual field boundaries can be visualized by placing the white and green boundary lines on the left and right sides of the player's face, centered on the blue face vector, starting from the measured position of the player's head. Similarly, the gaze vectors shown in red and the points of collision with the gaze vectors can also be visualized. The gazing points can be visualized by placing spherical objects at the coordinates of the recorded gazing points. In Figure 2, multiple blue balls represent the fact that many of the gazing points are located near the head of the red-clad player on the right side.

6.4. Skeletal Information Estimation with OpenPose

The proposed system uses OpenPose to estimate skeletal information from video captured by an external camera and introduces a method to determine the position of the experiment participants by combining the estimated head position and position information recorded by the HMD.

However, the original trained model of OpenPose often fails to estimate the head of the person wearing the HMD, and if the head estimation fails, the aforementioned epipolar constraint cannot be used. We used the extended OpenPose to perform additional training of OpenPose on the image dataset of the HMD wearer. The dataset was created by photographing the subjects in various backgrounds and clothing, taking into account the possibility that the accuracy of the model may be affected by differences in lightness, darkness, and angle.

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Figure 12: Experiment situation[19].

The subjects wore HMDs (VIVE PRO EYE). Photographs were taken from the front and from the side.

The estimation results before and after additional learning are shown in Figure 10. The post-learning model can estimate the head including the mouth, ears, and eyes, as shown in Figure 5.2.

6.5. Experimental procedure

In this section, we describe the experimental procedure.

Twenty-five members of the University of Tsukuba men's basketball team, ranging in age from 19 to 21, participated in the experiment as participants 1 through 25. All participants had previous basketball experience.

First, the participants were given an overview of the study, the eye gaze data to be acquired, and the fact that the data would be recorded by an external camera. Next, we explain that the range of movement for the participants during the experiment is a circle with a radius of 2 meters. To allow participants to confirm the range of movement, the range of movement is taped on the ground in advance. Figure 12 shows the situation during the experiment.

We explain how to handle the HMD and have the participants try it on as a test. Next, we played scenario 1 for practice in order for the participants to confirm the area in the VR virtual space in which they can engage in activities and to understand the behavior of the system. After the scenario is finished, we let the participants experience a range of movement of about three steps with the VR gymnasium displayed.

Explain the simulation experience and the number of attempts made during the simulation experience. Request the red team to defend against the red team's offense. During the experiment, an external camera will be used to record the experimenter playing each of the five scenarios described in section 6.2 four times, for a total of 20 scenarios. Make sure that there is no sequential effect when playing the scenarios. Explain that after each play is completed, the experiment participants should return to the initial position.

7. Results and Discussion

In this chapter, we visualize the results of the experiment and analyze them based on the indicators described in Chapter 3.

7.1. Object being watched

Figure 13 shows a summary of the participants' judgment counts of gazing objects in all scenarios. The horizontal axis is the name of the gazing object, and the vertical axis is the number of collisions between the gaze vector and the target. This figure shows that the objects that collide most frequently with the player's center of gaze are not other players or balls, but the background, the walls and floor of the gymnasium. Because he is playing defense, he pays more attention to the opposing offensive players than to his own teammates. We also see that he pays very little attention to the ball. There are two possible reasons for this. First, VIVE EYE uses eye movements to estimate the line of sight, and the system records the center point of the line of sight. Objects that collide with the center of gaze are recorded, but instead of the participant looking directly at the players, he or she may be looking between them at all times so that the two offensive players are in his or her field of vision at the same time. Previous studies of human vision have indicated that peripheral vision processing is an important part of information gathering. [14][15]. Another factor may be that by looking at the players of the opposing team, we can see how they are moving the ball and can gather information without intentionally looking at the ball.

Figure 14 shows the ratio of gazing objects from participant 1 to participant 10 in Scenario 3. In Scenario 3, Red 2 is out of the participant's field of view, so the par-

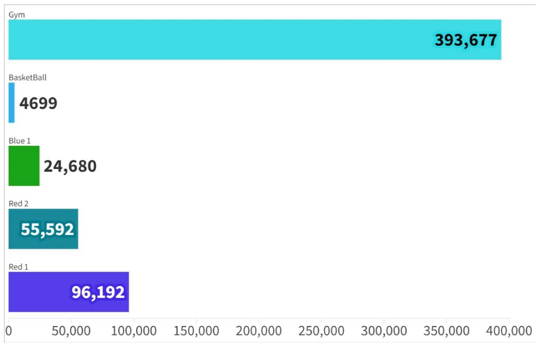

Figure 13: Number of gaze determinations in all scenarios.

ticipant has two choices. One is to keep shaking his head and always collect information about the two players. The other is to retreat and keep a distance so that Red 1 and Red 2 are visible at the same time. Participants who chose to turn their heads without retreating tended to focus on the players, whereas participants who retreated and looked at the two red team players simultaneously tended to look between the two red team players. From this figure, it can be analyzed that participants 3, 5, and 8 pay particular attention to the players. Participants 1, 9, and 10 are the ones who look at the gym most often. These participants are considered to be looking between two offensive players.

Next, Table 1 shows the average number of times participants looked at the NPCs in Scenario 2. Here we take the data of participants 3, 5, and 8, who tend to gaze at the red team, and participants 1, 9, and 10, who look between the offensive players. From this table, we can see that the participants collected information better from Red 1. In addition, participants 3, 5, and 8 gazed at the players more frequently than participants 1, 9, and 10.

Table 1
Number of times subjects visually observed NPCs in scenario 2.

Subject Number	Red 1	Red 2	Blue 1
Subject 1	6.25	2.25	1.25
Subject 3	**8.50**	**2.00**	**5.25**
Subject 5	**7.75**	**2.75**	**5.50**
Subject 8	**6.75**	**3.75**	**3.50**
Subject 9	6.75	1.25	3.75
Subject 10	5.25	1.75	2.25

Table 2 shows the average number of times participants saw the NPC in scenario 3. There is a difference in the scenarios between Table 1 and Table 2 in terms of whether Red 2 and Red 1 are visible at the same time, and by comparing the two tables, it is possible to analyze the players' information gathering methods. Table 3 shows the results of subtracting the values in Table 2 from Table 1.

Table 2
Number of times subjects visually observed NPCs in scenario 3.

Subject Number	Red 1	Red 2	Blue 1
Subject 1	5.00	3.25	1.25
Subject 3	8.25	2.25	5.50
Subject 5	8.25	3.25	5.25
Subject 8	7.25	4.00	3.75
Subject 9	6.50	1.50	3.75
Subject 10	5.00	1.50	1.75

In scenario 3, Red 2 is outside the participant's field of view. In this experiment, we observed three methods of gathering information from the participants. The first was to collect information by repeatedly shaking their heads, the second was to retreat so that they could see both members of the red team, and the third was to look at Red 2 only when necessary and focus mainly on Red 1, who had the ball from the beginning. Participants 3, 5 and 8 chose the method of gathering information while shaking their heads, while participants 9 and 10 chose to retreat. Participant 1 chose the third method, "Look at Red 2 only when necessary. The change from Scenario 2 to Scenario 3 revealed that Participant 5 increased the number of times he looked at Red 1 and Red 2 in particular. Participant 8 also increased the number of times he gazed at Red 1. In contrast, participants 9 and 10 did not change significantly. Participant 1 gazed at Red 1 less frequently and paid more attention to Red 2 in contrast to Red 1. The reason for this may be that the players increased the number of times they gazed at Red 2 in response to the longer time they spent gazing at Red 1.

Table 3
Changes in Table 2 compared to Table 1.

Subject Number	Red 1	Red 2	Blue 1
Subject 1	-1.25↓	1↑	0
Subject 3	-0.25	0.25	0.25
Subject 5	1↑	0.5↑	-0.25
Subject 8	0.5↑	0.25	0.25
Subject 9	-0.25	0.25	0
Subject 10	-0.25	-0.25	-0.5

Figure 15 shows the average time participants took each time they switched their visual targets in Scenarios 4 and 5. This figure shows that Participant 1 was particularly quick to switch gazing targets, and the results in Table 3 suggest that Participant 1 only captured the minimum necessary amount of information for Red 2. In contrast, Participant 9's style of play was to stop looking between Red 1 and Red 2 each time he switched his gaze to Red 1 and Red 2, and to collect more information.

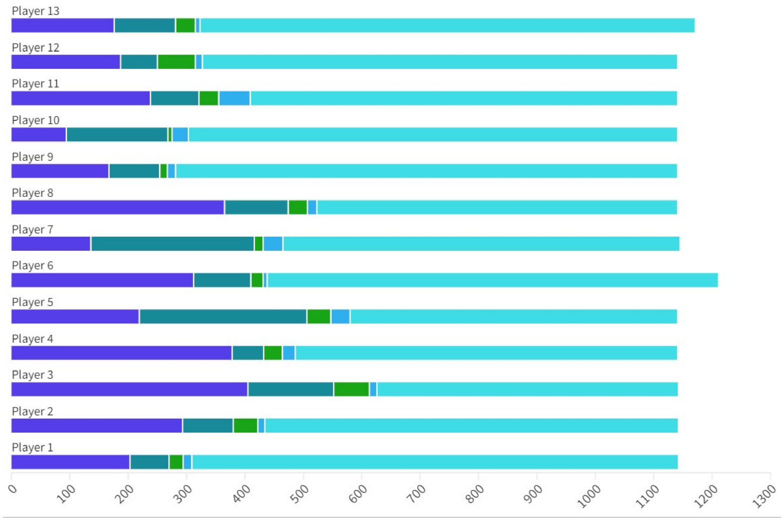

Figure 14: Subject's Proportion of fixation target in Scenario 3.

Participants 8 and 10 balanced themselves, and changing targets after grasping information from one person was considered to be the reason why it took them longer to do so. We also observed participant 5 in a replicated game situation, and the reason why he took longer to change targets compared to the other participants was thought to be due to his lower head rotation speed.

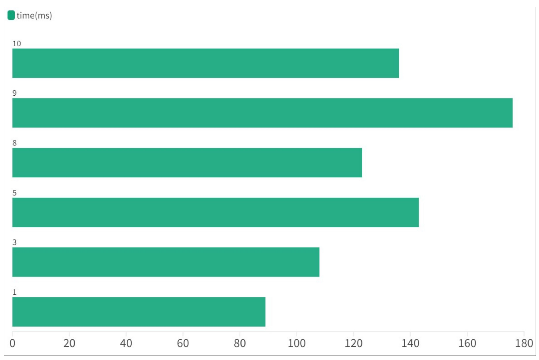

Figure 15: Time taken to change visual target in scenario 4 and 5.

These results allow us to analyze the characteristics of the information gathering methods of participants 1, 3, 5, 8, 9 and 10. Participant 1 pays attention to the area around Red 1, who has the ball, and pays attention to obtain at least the minimum information about the location of Red 2 when necessary. Participants 3, 5, and 8 move their eyes to keep track of the surroundings and pay attention when the opponent moves, such as passing or dashing. Participants 9 and 10 adjust their own positions to gather information during the game and tend to keep both offensive players in view, but participant 10 can be analyzed as a balancing type who pays more attention to the space between players than participant 9.

7.2. Numbers of Looking Back

Table 4 shows the number of head-turns for participants 1-5 in scenarios 1-5. The table shows that the number of head turns increases as the complexity of the situation increases for the participants in the games in the scenario. It also shows that participants 3 and 5 constantly move their eyes and also turn their heads, which is a characteristic of information gathering for participants 3 and 5 described in section 7.1.

7.3. Body movements

Figure 16 shows an image of the distance between each participant's joints. On the left is the experiment and on the right is a bar chart of the distances between the joints. The horizontal axis is the part to be measured and the vertical axis is the corresponding length. By continuing to record such data, the rate of change of the inter-articular distances can be determined and the intensity of the players' movements can be evaluated.

Figure 17 shows the distance between the joints of participant 22 for each frame in Scenario 3. The vertical axis is the distance between the joints for the horizontal frame. The reason for the longer distance between the

Table 4
Number of head turns for subjects in scenarios 1-5.

Subject Number	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
Subject 1	1.25	2.25	3.25	4.50	6.25
Subject 2	0.75	2.50	3.75	4.25	5.25
Subject 3	1.50	2.50	4.25	5.75	5.50
Subject 4	1.25	1.75	3.75	5.50	5.75
Subject 5	1.50	2.75	4.25	5.75	5.75

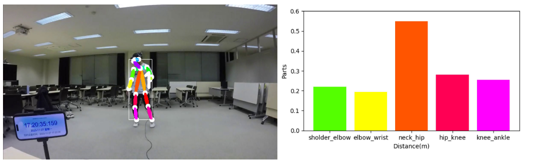

Figure 16: Distance between each joint.

joints in the later frames compared to the first frame can be attributed to the fact that the player initially assumed a defensive posture against Red 1, but Red 1 passed the ball to Red 2, who then made a defensive move against the shot by Red 2.

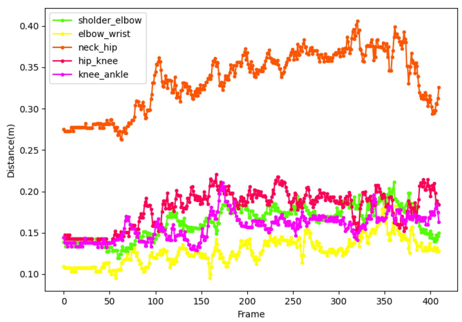

Figure 17: Distance between the joints of subject 22 in scenario 3 [19].

Figure 18 shows the rate of change of the distance between the joints of participant 22 with respect to the frame in scenario 3. As mentioned in Section 6.2, in Scenario 3, Red 1 passes the ball to Red 2, who is in the participant's visual field, indicating that the participant has a defensive intention.

7.4. Migratory trend

Previous studies have shown the potential for players to reproduce their route choices and analyze their tactical decisions during a match[16][17]. Figure 19 shows the head position of participant 15 in scenario 4 for a single play. The colors change from red to blue with time. Since the initial position of Red 2 is to the right of the participant's initial position, it turns out that the participant has a tendency to defend his mark rather than go for help.

Figure 20 and Figure 21 show the distance between Red 1 and Red 2 during a single play of Participant 15 in Scenarios 2 and 3. It shows the tactic of participant 15 keeping his distance when he cannot see Red 1 and Red 2 at the same time and approaching to defend as soon as his mark receives the ball, whereas Red 2 is within his field of view in scenario 2.

7.5. Average Situation Analysis Time

Figure 22 shows the average situational analysis time of the participants in Scenarios 4 and 5. Note that the average situation analysis time refers to the time between when a player sees an opponent's pass or feint and when his body begins to move. It was noted that a human needs about 150 ms to grasp the image he sees. [18]. From this figure, it was found that it takes time for the participants to process the image after their eyes see it in order to analyze the situation. In the previous section, we will discuss and analyze the data of participants 3, 5, and 8 and participants 1, 9, and 10. The figures suggest that participants 3, 5, and 8, who turned their heads more frequently and often looked at the players, had a shorter decision time than participants 1, 9, and 10. The reason for this may be that the participants who chose to retreat and grasp the overall information of the game need to process the information as well, while they have the advantage of being able to collect a lot of information. Another possible reason for the low situation analysis time of Participant 5 in Scenario 4 is that he was constantly moving his body and reaching for the opponent's hand at the moment the opponent was about to take action.

7.6. Discussion

In this experiment, an immersive scenario was presented to provide the same experience as a real game, and participants' eye gaze and body information were collected with the aim of evaluating players' ability to respond to situations using a number of indicators. The aforementioned

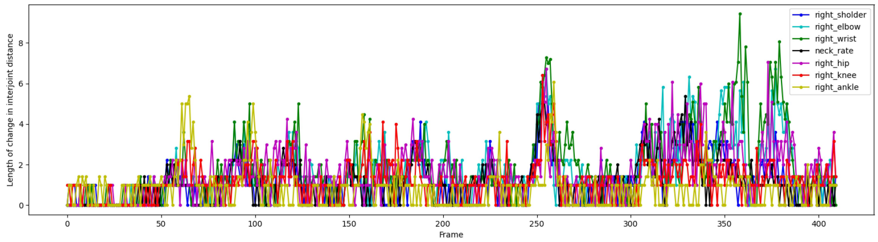

Figure 18: Rate of change in inter-joint distance.

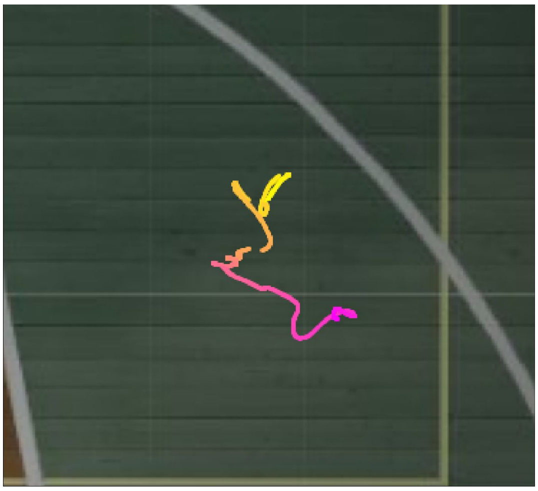

Figure 19: Route map.

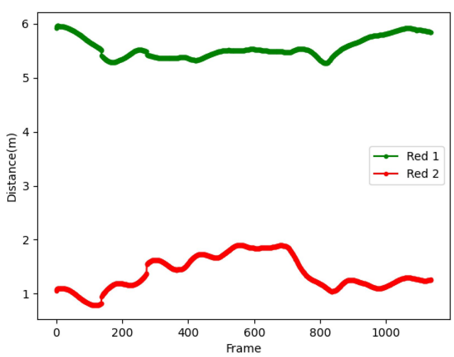

Figure 20: Distance between subject 15 and the two members of the red team in scenario 2 [19].

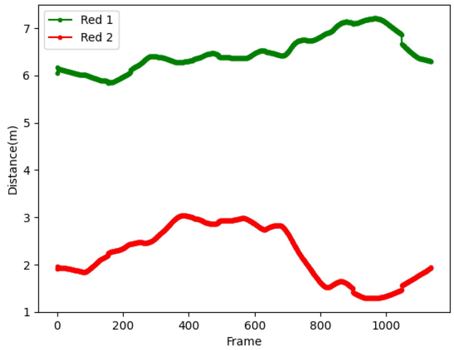

Figure 21: Distance between subject 15 and the two members of the red team in scenario 3 [19].

indicators were used to analyze the players' willingness to defend and help, and the tendency to move and the tendency to make tactical decisions were evaluated with the information collected from their gaze. Therefore, it can be said that the method used in this study can be used to evaluate the players' ability to respond to situations.

In this experiment to evaluate situational readiness, we did not analyze the complete three-dimensional posture of the participants, and there were cases in which decisions could not be made when the limbs were in front of or behind the head. It will be necessary to verify the effectiveness of the method of evaluating the complete three-dimensional posture with multiple cameras in order to fully understand the body information of the players.

8. Conclusion

We proposed an evaluation method that is useful for basketball players' ability to respond to complex situations using a VR simulator. We also conducted an evaluation

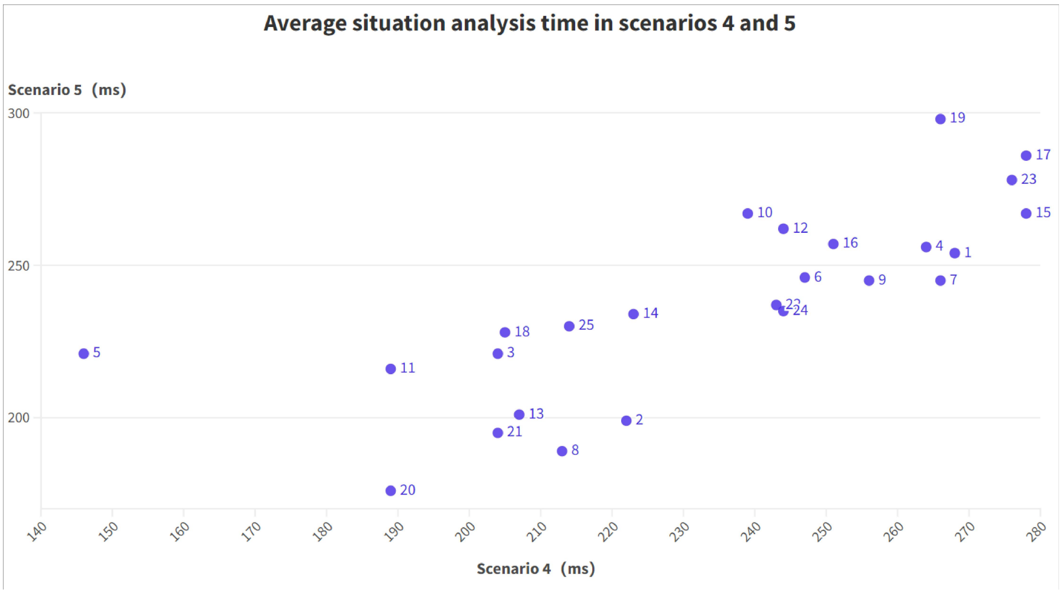

Figure 22: Average situation analysis time in scenarios 4 and 5 [19].

experiment based on the proposed index.

We invented a new index and an evaluation method to evaluate players' ability to respond to situations based on their gaze information and body movements. We constructed a system that can reproduce a realistic game situation using a VR simulator so that players can make decisions that are equivalent to those they would make in a game. We prepared scenarios to evaluate the players' ability to respond to situations.

The evaluation experiments were conducted, data was acquired by the proposed system, and trends in player evaluations and behavior were analyzed.

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