Simulated Visual Field Narrowing in VR to Induce Changes in Visual Exploratory Activity in Soccer

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Abstract

Visual field narrowing is regarded as a factor that limits visual exploratory activity in soccer. In this study, we propose a method that simulates visual field narrowing in a VR soccer simulation. This simulated visual field narrowing is realized by applying blur to the peripheral visual field region. In an evaluation experiment, we compared conditions with and without the simulated visual field narrowing and measured the number of head turns, which indicates the frequency of visual exploratory activity, and the head-turn amplitude, which indicates its quality. As a result, the participants tended to increase the number of head turns to compensate for the missing information under the simulated visual field narrowing. In contrast, the head-turn amplitude showed individual differences. This suggests that the adaptation strategy adopted when visual field narrowing occurs differs among participants possibly depending on differences in their skill and psychological capacity.

Keywords

Visual Exploratory Activity, Visual Field Narrowing, Virtual Reality, Soccer Training, Head Movement Analysis

1. Introduction

In soccer, visual exploratory activity, through which a player quickly and accurately grasps the surrounding situation such as the positions of opposing players, teammates, and the ball, plays an important role in the player's cognitive and decision-making processes during a match [1][2][3]. One factor that limits visual exploratory activity in soccer is visual field narrowing. Visual field narrowing is known as an effect in which the focused field of view becomes narrower owing to psychological factors and the like [4]. Whether such visual field narrowing can also occur in soccer, and, if it does, how it affects a player's visual exploratory activity, remains to be investigated. Such an investigation requires accurate measurement of the given instructions, the visual stimuli, and the resulting behavior.

To date, visual exploratory activity has been investigated using VR simulations [5][6][7][8][9]. Investigating the relationship between visual exploratory activity and visual field narrowing requires detailed measurement under conditions in which the player is consciously trying to perceive the situation. In this case, the visual stimulus presented as visual field narrowing must have accurate reproducibility and strict control.

We propose a method that simulates visual field narrowing by applying blur to the peripheral visual field region in a VR simulation[1]. The purpose of inducing this condition in VR is not to disadvantage players but rather (i) to allow players and coaches to observe adaptation behavior to visual field narrowing that is otherwise unobservable in real matches, and (ii) to provide a controlled stimulus for training compensatory scanning behavior under degraded peripheral vision. Furthermore, by having participants perform the task under both conditions, with and without the simulated visual field narrowing, and by measuring and comparing the number of left-right head turns and their amplitude, which represent the frequency and quality of the player's visual exploratory activity, we clarify the relationship between visual field narrowing and visual exploratory activity in soccer.

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2. Related work

2.1. Visual Exploratory Activity in Soccer

In sports, perceptual and cognitive skills have been reported to be important factors that determine performance during a match [1][2][3].

Vaeyens et al. [11] investigated the relationship between the quality of tactical decision-making and visual exploratory activity. Their study showed that, in order to make accurate decisions, it is essential to frequently switch the point of gaze by moving the eyes.

2.2. Changes in the Visual Field in Sports

Changes in the visual field during and after exercise in sports have also been investigated. Hobson and Henderson [12] conducted one of the earliest studies on visual field changes in athletes and reported that physical fatigue could temporarily affect the extent of the visual field.

According to Easterbrook's cue utilization hypothesis [4], when factors such as heart rate and stress increase, the range of attention narrows, and a perceptual narrowing occurs in which processing resources concentrate on the important information at the center while the processing of peripheral information is suppressed.

2.3. Cognitive Load and Visual Field Narrowing

Human visual exploratory activity changes not only with physical exercise intensity but also with cognitive and psychological load. In particular, it has been widely reported in traffic psychology and ergonomics that an increase in cognitive load causes a narrowing of the focused field of view and a concomitant change in visual exploratory activity. Recarte et al. [13] measured the gaze behavior of drivers while they performed tasks such as mental arithmetic during driving. They found that, under conditions of high cognitive load, a spatial gaze concentration occurs.

A similar phenomenon has also been confirmed under high-pressure situations in sports. Williams et al. [14] reported that, in karate athletes with high anxiety levels, the fixation point becomes fixed on specific information sources such as the opponent's attacking limbs, and Wilson et al. [15] reported that, under anxiety conditions in soccer penalty kicks, players gaze longer at the threatening opposing player, leading to a decline in performance.

These studies indicate that, under conditions in which visual field narrowing occurs owing to psychological load and the like, gaze shifts decrease and visual exploratory activity is affected. Quantifying visual exploratory activity under visual field narrowing conditions, as we do in this study, is significant for elucidating, at the cognitive and behavioral levels, the factors behind the decline in player performance under high load.

2.4. VR Simulation of Sports

VR-based skill training for sports has been developed. For example, Cesar et al. [6] proposed a VR-based system for soccer as training to measure visual exploratory activity and to shorten the reaction time when executing passes. In their evaluation experiment, the player's head direction obtained from the HMD was classified into three areas, and visual exploratory activity was evaluated from the proportion of time the player faced each direction. However, this method treats head direction as discrete areas and does not capture the detailed characteristics of the movement. In contrast, in this study we obtain the head rotation angle from the HMD as a continuous value, compute the amplitude of the exploratory activity from these data, and quantify the number of head turns by performing peak detection on the waveform data. This enables a more detailed analysis that includes not only the proportion of facing direction but also dynamic characteristics such as the intensity and frequency of the exploratory activity.

Ishikawa et al. [16] utilized measured player position data in a VR simulation for visual training of basketball players. Referring to this approach, in this study we also utilize player position data measured during soccer matches to give tactical realism to the movements of the players in the VR simulation.

3. Simulated Visual Field Narrowing Method in a VR Simulation

We adopt the method of applying blur to the peripheral visual field region. Blur processing has the property of attenuating the visual resolution of the image while preserving information such as color and motion. Therefore, we consider that it is highly valid as a reproduction of the state in which, under high load, the brain suppresses detailed information processing of the peripheral vision and perceives only a rough outline of objects. Because the visual field narrowing assumed in this study changes dynamically according to the load placed on the player, a method that applies blur over a fixed region size, such as existing foveated rendering [17], is inappropriate for realizing the blur application for the simulated visual field narrowing. We realize the simulated visual field narrowing by dynamically changing the region to which blur is applied according to the gaze coordinates and the movement speed.

3.1. Situations in Which Visual Field Narrowing Is Expected

We selected, as the situation in which the simulated visual field narrowing is presented, the phase of penetrating into the opponent's penalty area to aim for a goal. In this phase, accurate visual exploratory activity is essential for split-second decisions, while pressure from opposing players increases cognitive and psychological load and tends to induce visual field narrowing; we therefore consider it to be suitable for verifying the proposed method.

3.2. Blur Control According to Gaze

As shown in the left in Figure 1, we implement a system that dynamically changes the blur region according to the gaze point.

At each frame, the distance from the gaze point to each pixel is computed; for pixels outside the focused field of view region, a color obtained by taking a weighted average of horizontally neighboring pixels using weights based on a Gaussian blur [18] is output, whereas for pixels inside the region, the color is output unchanged. This processing is applied to all pixels in real time.

3.3. Blur Control According to Speed

The simulated visual field narrowing in this study changes the blur strength and the focused field of view region according to the speed of the user moving in the VR space, as shown in the right in Figure 1. As the running speed increases, the blur strength applied to the peripheral vision is increased while the clearly rendered focused field of view region is progressively narrowed.

Figure 1: Blur control by gaze direction and speed change. The yellow area corresponds to the focused field of view region which is attached to the gaze point.

3.4. Application of Blur

The gaze point obtained by eye tracking is mapped to the coordinate system in the screen space and passed to the shader. Inside the shader, the Euclidean distance d to the target pixel from the gaze point is computed.

If the distance d is smaller than the threshold R, the parameter set as the extent of the focused field of view region, the target pixel color is output unchanged. Otherwise, the pixel is treated as belonging to the visual field narrowing region, and blur processing is applied. The blurring is operated in horizontal basis to simulate the moving on the flat ground surface. The reference horizontal size on blurring calculation is controlled by the threshold parameter S.

Through the above operations, blur such as that shown in Figure 2 can be given. This operation is done on-line, per-frame.

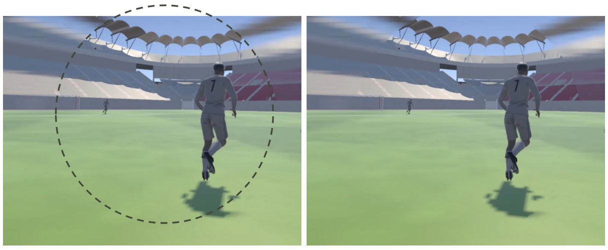

Figure 2: Blur application. The black dotted circle in the left picture indicates rough boundary of blurring defined by R. The center of the circle corresponds to the gaze point. Participants see VR world as shown in the right picture.

4. Evaluation Method

4.1. Quantitative Evaluation

To verify the effect of the simulated visual field narrowing on the user's visual exploratory activity, we use two quantitative evaluation indices: the frequency of head rotation and the amount of rotation per turn. As for the specific measurement method, the horizontal rotation angle (yaw) is recorded as a time series from the HMD rotation data during measurement. By applying peak detection to the acquired angle data, intentional head-turn motions are extracted.

First, from the total number of extracted peaks, the frequency of head turns performed by the user to check the surrounding situation is computed. This is to verify whether the number of visual exploratory activities increases to compensate for the shortfall when the amount of visual information decreases owing to visual field narrowing. Next, by computing the amplitude of each extracted head turn, we evaluate how wide the field the user checked in a single head turn. Through this, we analyze the characteristics of the user's visual exploratory activity.

4.2. Subjective Evaluation Questionnaire

In addition to the quantitative data, we conduct a subjective evaluation using a questionnaire to capture the user's internal changes and sensations. For the response format, we use a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The questions are set with a focus on changes in awareness of visual exploratory activity under restricted vision and on self-evaluation of the quality of one's own visual exploratory activity and situational awareness. Through this, we verify changes in the user's psychological burden and exploration strategy that cannot be measured by quantitative data alone.

As the questionnaire analysis involves five items, these results should be interpreted as exploratory; with a Bonferroni correction ($\alpha = 0.01$), only Q2 remains significant.

5. Evaluation Experiment

5.1. Trend of Changes in the Number of Head Turns in the VR Simulation

As a preliminary step, we conducted an experiment to examine the change in head turns when participants experienced the same VR simulation scenario twice in succession. The participants were three men in their twenties with normal vision. The results are shown in Table 1. No statistically significant difference was observed, although the small sample size (N=3) limits the strength of this conclusion; we treat this as preliminary evidence that mere repetition does not systematically alter visual exploratory activity.

Table 1
Trends of changes in head turns across repeated trials.

Index	1st attempt	2nd attempt	difference	p value	result
Number of turns [count]	15.3	15.7	+0.3	0.750	n.s.
Amplitude [degree]	45.7	81.8	+36.0	0.250	n.s.

5.2. Experimental Procedure

We conduct an experiment to clarify the relationship between visual field narrowing and visual exploratory activity in soccer. The participants were 11 people including men and women in their twenties with normal vision. The VR simulation was presented on a Meta Quest Pro head-mounted display. Participants moved through the VR space by operating the thumbstick on the handheld controller, and the gaze point used for the blur control was obtained by the eye-tracking function built into the Meta Quest Pro. The presence or absence of the proposed simulated visual field narrowing is taken as the variable; the condition without the simulated visual field narrowing is the control condition, and the condition with it is the intervention condition. A within-subjects design is adopted, and by having each participant perform both the control and intervention conditions, the influence of individual differences in ability and in awareness of visual exploratory activity is minimized. In addition, counterbalancing is performed to eliminate order effects.

The evaluation indices can be classified into the following two types. First, as objective indices, we use the number of left-right head turns, which represents the frequency of visual exploratory activity, and the head-turn amplitude, which represents the quality of visual exploratory activity. Second, we use scores, based on the subjective evaluation questionnaire, for the participants' awareness of visual exploratory activity and the self-evaluation of their own visual exploratory activity. The questionnaire items are shown in Table 2.

The flow of the experiment is as follows. The participant first experiences the soccer VR simulation under one of the conditions and then answers the subjective evaluation questionnaire; the same procedure is repeated under the other condition.

Table 2
Questions on the questionnaire.

ID	Sentence
Q1	I was aware of checking my surroundings
Q2	I realized that there is information beyond my field of vision
Q3	I felt that visual search movements were important for understanding the situation
Q4	I was able to get a good grasp of the situation around me
Q5	My own visual search movements were insufficient

5.3. Verification of Changes in Visual Exploratory Activity by the Proposed Method

We verify the change in each participant's visual exploratory activity between the control and intervention conditions. The change in the number and amplitude of head turns for each participant is shown in Figure 3 left, and the average of the results of the 11 participants is shown in Table 3. As a result of the experiment, regarding the number of head turns, Figure 3 left shows that 7 of the 11 participants, i.e., 64%, exhibited an increase. Table 3 shows that the change in the participants' mean number of head turns was an increase of 4.6. A Wilcoxon signed-rank test gave $p = 0.092$, which does not reach significance at the 5% level but suggests an increasing tendency ($p < 0.10$, exploratory). Regarding the head-turn amplitude, Figure 3 left shows that 6 participants increased and 5 decreased. Analyzing the mean head-turn amplitude, Table 3 shows that the mean change was -0.4 degrees, indicating almost no difference. A Wilcoxon signed-rank test gave $p = 0.831$, indicating no significant difference.

The results show that the participants tended to compensate for the information shortfall by increasing the number of head turns in response to the restriction of visual field narrowing. This is considered to result from the visual field narrowing reducing the information in the peripheral visual field region, thereby raising the participants' awareness of overlooking surrounding information. On the other hand, no significant difference in head-turn amplitude was observed for the participants. However, focusing on individual changes, the participants were divided into a group whose amplitude increased and a group whose amplitude decreased, revealing individual differences. This is considered to suggest that the quality of visual exploratory activity does not automatically improve from a sense of crisis about overlooking information alone, and that the adaptation strategy when visual field narrowing occurs differs depending on each participant's skill and their capacity to cope with psychological load.

Table 3
Changes in visual exploratory activity with and without simulated visual field narrowing.

Index	control (wo)	intervention (w)	difference	p value	result
Number of turns [count]	20.6	25.2	+4.6	0.092	†
Amplitude [degree]	72.0	71.6	-0.4	0.831	n.s.

†: $p < 0.10$ (exploratory), *: $p < 0.05$, **: $p < 0.01$.

5.4. Subjective Evaluation Questionnaire

The results of the subjective evaluation questionnaire are shown in Table 4. The results show that, for the questions asking about changes in awareness of visual exploratory activity, the scores increased under the intervention condition in all three items. In particular, Q1, which asks about awareness of checking one's surroundings, showed a significant difference ($p = 0.017$), and Q2, which asks about the realization that information exists beyond one's own field of vision, showed the strongest difference ($p = 0.003$), suggesting that the proposed simulated visual field narrowing effectively conveys the risk of overlooking surrounding information. For the questions asking about self-evaluation of the quality of one's own visual exploratory activity and situational awareness, in Q4, which asks about the participant's own sense of having grasped the situation, the score decreased under the intervention condition, whereas in Q5, which asks about a sense of insufficiency in one's own visual exploratory activity, the score increased under the intervention condition. This suggests that, under conditions in which visual field narrowing occurs, it becomes harder to give the participant confidence that they have grasped the surrounding situation.

Therefore, it can be said that the proposed simulated visual field narrowing prompted a more cautious self-evaluation of one's own visual exploratory activity. A Wilcoxon signed-rank test showed a significant difference for Q4 ($p = 0.038$) but no significant difference for Q5 ($p = 0.230$). Because the proposed simulated visual field narrowing is not sufficiently effective at prompting reflection on one's own visual exploratory activity, objective feedback is considered necessary for further improvement of visual exploratory activity.

Table 4
Subjective evaluation by the questionnaire.

ID	control (wo)	intervention (w)	difference	p value	result
Q1	4.91	6.27	+1.36	0.017	*
Q2	4.09	6.55	+2.45	0.003	**
Q3	4.91	6.55	+1.64	0.011	**
Q4	5.18	4.55	-0.64	0.038	*
Q5	3.09	3.82	+0.73	0.230	n.s.

5.5. Adaptation Strategies for Visual Field Narrowing and Discussion

From the verification of changes in visual exploratory activity by the proposed method, the number of head turns under the simulated visual field narrowing showed an increasing tendency but no significant difference, while the head-turn amplitude showed a polarized result. While an overall increase in head turns under restricted peripheral vision is intuitively expected, our contribution lies in quantifying *how* individuals adapt, which was not uniform across participants. Since this suggests that the adaptation strategy for visual field narrowing differs among participants, we analyze each participant's adaptation strategy from the changes in visual exploratory activity.

Figure 3 right summarizes the changes in the number and amplitude of head turns under the proposed method. As Figure 3 right shows, the participants can be divided into a group that increased both the number and amplitude of head turns, a group that increased only the number while the amplitude decreased, a group that increased only the amplitude while the number decreased, and a group that decreased both the number and amplitude. Here, we refer to these groups, in order, as the Adaptive group, the Superficial group, the Cautious group, and the Suppressed group.

Based on the above classification, we discuss the adaptation strategy of each group and the underlying factors. First, the Adaptive group represents an ideal adaptation to visual field narrowing; these participants are considered to have increased the number of head turns and, by turning their heads through a wide amplitude, to have compensated for blind spots in response to the risk of overlooking surrounding information. For the Superficial group, the participants are considered to have increased the number of head turns out of a sense of crisis about overlooking surrounding information, but, owing to haste, the amplitude became shallow, so that a sufficient field of view was not ultimately secured. For the Cautious group, the participants are considered to have emphasized the quality of visual exploratory activity upon becoming aware of overlooking surrounding information, increasing the amplitude while concentrating on each individual head turn. For the Suppressed group, the participants are considered to have been unable to adapt to the increased cognitive load, so that the visual exploratory activity itself decreased.

From the above, it is suggested that the proposed method may help characterize a soccer player's adaptation strategy to visual field narrowing. Although the small number of participants per group (2–3) and the absence of expertise and task-performance measures preclude validating this taxonomy as a diagnostic tool at this stage, it offers a working hypothesis for individualized coaching, to be verified in future studies with larger samples, expertise profiling, and performance metrics such as decision-making accuracy.

We further note several limitations. First, the proposed method externally removes peripheral visual information, whereas psychological visual field narrowing is an endogenous attentional phenomenon. Our simulation should therefore be regarded as reproducing the informational consequences of visual field narrowing rather than its cognitive mechanism, and the behavioral adaptations observed here may differ from those under genuine stress-induced narrowing. Second, because the blur intensity is coupled with locomotion speed, differences in movement speed between the two conditions could act as a confounding factor; as movement speed was not logged in the present experiment, speed logging and matching between conditions will be incorporated in future experiments. Third, the participants' soccer expertise was not systematically assessed, which limits the interpretation of the observed individual differences in terms of skill.

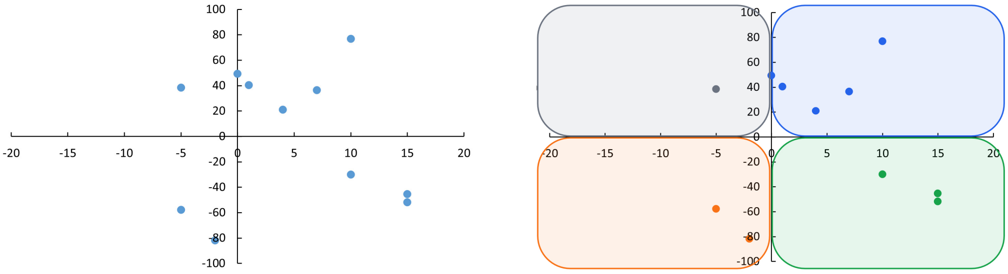

Figure 3: Analysis of the experimental result. Left: Changes in visual search behavior induced by simulated visual field narrowing. Right: Adaptive strategies where blue indicates adaptive, green superficial, gray cautious, and orange suppressed respectively.

6. Conclusion

In this study, we proposed a method that simulates visual field narrowing by applying blur to the peripheral visual field region, and we compared the changes in players' visual exploratory activity according to the presence or absence of its application. As a result, the players tended to increase the number of head turns to compensate for the lack of information, while individual differences were observed in the head-turn amplitude, suggesting that the adaptation strategy for visual field narrowing differs among players. A future task is to apply the proposed method to the diagnosis of players' adaptation strategies and to individualized coaching.

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