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Immersive experience influences eye blink rate during virtual reality gaming

Abstract: *Virtual reality (VR) technology now provides players with immersive and realistic experiences as never before. Spatial presence plays a crucial role in the introduction of immersive experience in a VR environment. Spatial presence is a special feeling of personal and physical presence in the displayed environment. In this study, we found that the first-person perspective (1PP) was more effective in raising the sense of spatial presence that induces immersive experience compared to the third-person perspective (3PP) in a VR shooting game. Moreover, eye blink rate was significantly higher in the 1PP compared with the 3PP. The 1PP game setting was more realistic than the 3PP setting, and may have raised participants' sense of immersion and facilitated eye blink. These results indicate that eye blink rate is increased by the sense of spatial presence, and can be a good measure of subjective immersive experience in a VR environment. Neuroscientific evidences suggest that dopaminergic system is involved in such emotional experiences and physiological responses.*

Keywords: *virtual reality, gaming, eye blink, spatial presence, immersive experience*

Abbreviations: VR – virtual reality, 1PP – the first-person perspective, 3PP – the third-person perspective.

Introduction

One of the main factors attracting computer game players to computer games is the pleasure of being immersed in the realistic worlds of such games (Weibel & Wissmath, 2011). Spatial presence is a very important factor for the introduction of an immersive experience in a virtual reality (VR) environment (Wirth et al., 2007; Havanek et al., 2012). Spatial presence is a special feeling of "being there" that causes the players to believe that they are personally and physically present in the displayed environment.

VR technology has made great advances, particularly in sensor technologies that have enabled players to move by using VR goggles such as HTC Vive^{TM} (HTC Corporation, New Taipei City, Taiwan). Such VR technology has encouraged psychologists to conduct low-cost research in this field, which could not have been done until recently.

Self-motion is a key factor in enhancing spatial presence. Havanek et al. (2012) reported that the first person-perspective (1PP) is more effective in increasing spatial presence in video games than the third-person perspective (3PP). In the 1PP, the player plays from his or her own perspective according to what is seen on the visual display; while in the 3PP, he or she plays from an agent's perspective as the agent is shown in the display. Therefore, the 1PP is more realistic in a video game.

Spontaneous eye blink is associated with emotion and cognitive tasks. Ponder and Kennedy (1927) showed that eye blink rate increases in people who are angry or excited states. People tend to blink more often when they watch

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emotional movie rather than a neutral one (Koukounas & McCabe, 2001). Additionally eye blink rate varies depending on the type and difficulty level of tasks as well as mental workload. Studies have revealed that an increased level of the difficulty and workload reduces eye blink rate (for review, Jongkees & Colzato, 2016; Lean & Shan, 2012). For example, Zhang et al. (2015) found that eye blink rate increases as the accuracy score being improved in the Go/No-go task is improved. In addition, motivation and effort in a finger-tapping task enhanced eye blink rate with exerted effort in response to reward cues (Pas et al., 2014).

Enhanced spatial presence in a VR environment helps players become more emotional and motivated because of usability improvement and reduction of mental workload. Therefore, eye-blink is expected to become a useful physiological measure for the evaluation of spatial presence in a VR environment from the perceptions of emotion and cognitive tasks. However, such research has not been conducted yet.

In this study, we compared the eye blink rate of the players who played VR shooting games from two perspectives (the 1PP and the 3PP). Results showed that the 1PP significantly increased players' sense of immersion and their eye blink rates. This suggests that eye blink can be a good measure of a subjective immersive experience in a VR environment.

Materials and Methods

Participants

Fourteen male and three female college students (19–23 yrs.; mean age 21.9 yrs.) participated in the study. All were healthy and had normal or corrected-to-normal vision. They were right handed.

Written informed consent was obtained from all the participants after the purpose and procedures were explained. All of the experiments were performed following international ethical standards of WHO and institutional guidelines. The purpose and procedures were approved by the institutional ethical committee.

Apparatus and Procedure

Participants wore a head-mounted display (HTC Vive^{TM}), and palyed a custom-made VR shooting game. Two infrared sensors installed in the room automatically recognized a participant's ambulance and behavior (HTC Vive^{TM} Lighthouse). These sensors could track the position of the head-mounted display, into which the infrared light source was installed.

His or her body positions and postures were fed back to the computer so as to be synchronized with the view of the VR in the head-mounted display. Head motion sensors were also installed in the head-mounted display so that the VR view could be simultaneously adjusted to the participant's head position. A hand-held HTC Vive^{TM} controller collected the participant's gestures with the right hand and motion of the right index finger, and also fed back these data to the computer to control the gun and/or the avatar shown in the head-mounted display.

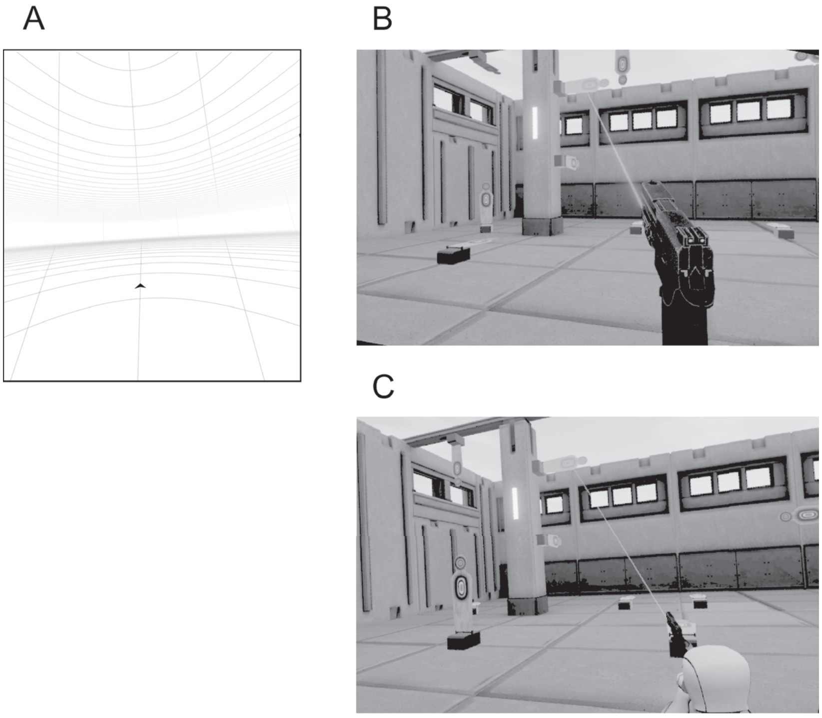
All the visual and auditory presentations were controlled by special applications programmed in Unity (Unity Technologies, San Francisco, CA, USA) and C# (Microsoft, Tokyo, Japan), running on a desktop computer equipped with Core i7 processor and gaming video card. The free images of gun, gymnasium, target and avatar were downloaded from Unity Asset Store (https://www.assetstore.unity3d.com/jp/#!/content/26689; https://www.assetstore.unity3d.com/jp/#!/content/2088; https://www.assetstore.unity3d.com/jp/#!/content/71229; https://www.assetstore.unity3d.com/jp/#!/content/4696, respectively).

To allow them to adapt to the VR environment, participants were asked to stand upright and watch a wire-frame spatial image with an arrowhead showing the direction of the center position for 180 s (Fig. 1A). The angle and direction of the image were synchronized with head movement. Immediately after this adaptation phase, participants started playing a VR shooting game from two perspectives (1PP and 3PP). In the 1PP, only a gun was shown on the head-mounted display, used to shoot targets appearing in the virtual gymnasium (Fig. 1B). The gun moved according to the movement of the hand-held controller, and fired a bullet when the participant pulled the trigger with his or her right index finger. To enhance the fidelity of VR, a shooting noise was presented through the headset and the hand-held controller vibrated when the trigger was pulled. In contrast, an avatar with a gun was shown in the 3PP. The motions of the avatar and the gun were synchronized with the participant's head position and posture (Fig. 1C). The shooting noise and vibration were also presented in the 3PP. Each participant played five 1PP and five 3PP VR game sessions in an alternating sequence. Each session ended after 90 s.

Eye blinks were recorded electrophysiologically with a small wireless amplifier (AvatarEEG, Eugene, OR, USA). Two silver dish electrodes (5 mm in diameter) were placed above and below the participant's right eye to measure the electrical activity of the muscles mediating eye blink (electromyogram). Eye blinks were continuously recorded during the VR shooting game sessions. Eye blink was recognized as a large sharp notch in the electrooculographic recording (Andreassi, 2007).

To evaluate sense of immersion, we used two 5-item physical presence subscales from a Japanese translation of the MEC-SPQ questionnaire (Vorderer et al., 2004). The original MEC-SPQ questionnaire consists of 9 subscales relating to spatial presence. The self-location and the possible action subscales are specifically intended to reflect physical presence (Havranek et al., 2012). The self-location subscale measures the participant's impression of being physically in the middle of the virtual environment. The possible action subscale assesses his or her impression of being able to act in such environment. The participants were asked to respond to these measures on a 5-point scale ("0 = I do not agree at all" to "4 = I agree fully") after completing all the VR sessions. Moreover, each participant was interviewed with an experimenter to ask his or her impression of the game after completing all the sessions.

Figure 1. The images shown on VR head-mounted display. The wire-frame spatial image with an arrow head for a participant's adaptation to VR environment (Fig. 1A). The shooting game images for the 1PP (Fig. 1B) and for the 3PP (Fig. 1C).



Statistical Analysis

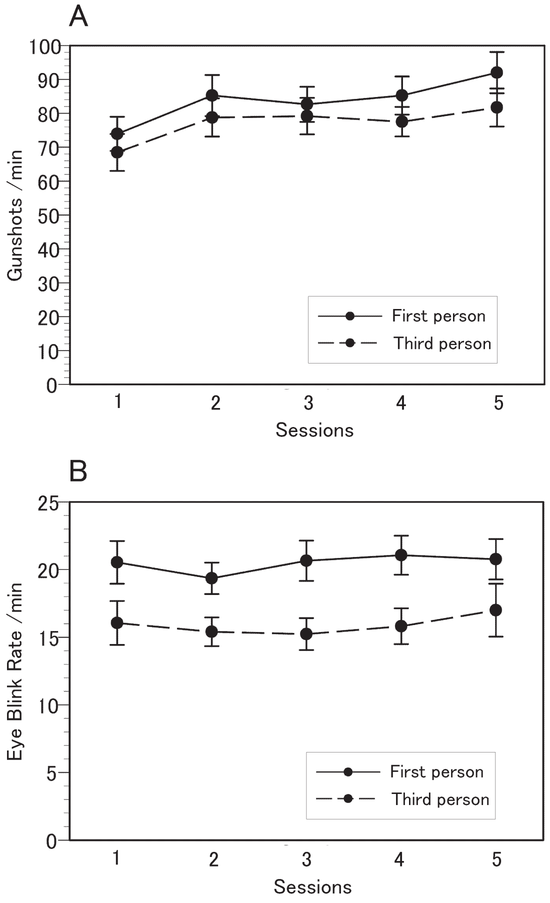
Statistical analysis was done with repeated two-way ANOVA (analysis of variance) for gunshot counts and eye blink rate to evaluate perspective and practice effects (2 perspectives vs. 5 sessions). Post-hoc tests were done with repeated one-way ANOVA, and followed by Bonferroni's multiple-comparisons. When sphericity was rejected, Hyunh-Feldt correction was used. Pearson's correlation coefficient was also calculated between gunshot count and eye blink rate. Statistical analyses of the summed points of items in the MEC-SPQ questionnaire subscales were done with paired t-test. Statistical significance was set at $p < 0.05$. The data were shown as the mean ± S.E. Data were analyzed using SPSS statistical software package (IBM SPSS ver. 22 for windows, Tokyo, Japan).

Results

Figure 2A shows that gunshot counts were significantly higher in the 1PP than in the 3PP ($F_{(1, 16)} = 15.84$, $p < 0.001$). Participants also fired less frequently in the first session than in subsequent sessions ($F_{(2.07, 33.18)} = 6.12$, $p < 0.005$). Post hoc tests showed a marginally significant difference between sessions 1 and 5 ($p < 0.03$) in the 1PP and between sessions 1 and 2 in the 3PP ($p < 0.015$). These results showed that the practice influences gunshot counts. No interaction was detected between two perspectives and sessions ($F_{(4, 64)} = 0.93$, ns).

Figure 2B portrays a conspicuous increase in eye blink rate in the 1PP compared with the 3PP ($F_{(1, 16)} = 34.57$, $p < 0.001$). There were no differences among the 5 sessions ($F_{(4, 64)} = 0.87$, ns) and no interaction between perspective

Figure 2. The variation of gunshots and eye blinks in consecutive sessions. The panels A and B show the gunshot count per min and eye blink rate per min, respectively.



(1PP and 3PP) and session ($F_{(4, 64)} = 0.87$, ns). These results demonstrated that practice does not have effect on eye blink rate in both perspectives.

A correlational study was performed to assess the effect of gunshots on eye blinks in the 5th session since results indicated that gunshot count significantly increased between the 1st and 5th sessions as shown above. Statistical results showed no significant correlation coefficient between gunshot counts and eye blink rate in the 1PP and the 3PP ($r = 0.46$, $n = 17$, ns; $r = 0.30$, $n = 17$, ns).

The MEC-SPQ questionnaire scores showed that the 1PP induced greater spatial presence than the 3PP (score = 26.65, SE = 7.40 vs score = 18.56, SE = 7.87, respectively). Statistical analysis revealed a highly significant difference between the 1PP and the 3PP ($t = 4.37$, $df = 16$, $p < 0.001$). In addition, the 1PP produced higher possible action scores than did the 3PP (score = 22.18, SE = 6.88 vs score = 15.41, SE = 6.86, respectively). Statistical analysis also yielded a very significant difference between the 1PP and the 3PP ($t = 4.68$, $df = 16$, $p < 0.001$). During the post-experimental interviews, all the participants stated that using 1PP for the VR game made it more fun and easy to play than the 3PP.

Discussion

In this study, findings showed that the 1PP induced spatial presence and possible action more than the 3PP. This sense of immersion caused an increase in gunshot count and eye blink rate. A previous questionnaire study by Havanek et al. (2012) previously revealed that the 1PP induced greater spatial presence and possible action in a commercial video game than the 3PP. In the present study, in the 3PP participants were required to manipulate an avatar that did not resemble them in appearance, while in the 1PP participants could play the shooting game by directly manipulating a gun. In the 3PP, the unrealistic appearance of the avatar and the task difficulty may have decreased participants' sense of immersion and eye blink rate, respectively. All the participants answered that the 3PP made it more difficult to play the VR game than the 1PP. Oh et al., (2012) reported that eye blink rate was increasingly suppressed as the task difficulty level increased. The 1PP game setting was more realistic than the 3PP setting, thus, the 1PP may have raised participants' sense of immersion and facilitated eye blink.

Eye blink rate has a close relationship with dopamine activity in the brain (Jongkees & Colzato, 2016). The higher the dopamine activity, the higher the eye blink rate. Moreover, activation of dopaminergic neurons has been shown to affect participants' emotional states in imaging studies of the human brain (Takahashi et al., 2015). The activity of dopaminergic neurons also correlates with performance of tasks (Takahashi et al., 2017). In a brain imaging study, Havanek et al. (2012) found that the limbic cortex was significantly activated in the 1PP compared with the 3PP. The limbic cortex controls emotion via the dopaminergic system (Burgdorf & Panksepp, 2006). Dopaminergic neurons also mediate task performance in the limbic cortex (Shiner et al., 2012). Therefore, the dopaminergic circuit in the limbic cortex is thought to activate emotional states and improve task performance that can be observed as an increase in gunshot count.

In physiological studies of VR, electrodermal activity (Brundage et al., 2016; Wiederhold et al., 2002), heart rate (Brundage et al., 2016), and electroencephalography (Vogt et al., 2016) have been employed as measures. The current study revealed that eye blink could also be a good physiological measure to evaluate the immersion experience in VR games. Although the eye blink was detected using an electromyogram in this study, a conventional strain gauge can also act as a cheap but reliable apparatus for this purpose. A sheet strain gauge is usually fixed around the eye using an adhesive tape.

Another two factors that are conceivably involved in the increased eye blink rate in the 1PP are task difficulty and eye blink reflex related with gun shooting. Difficulty level of tasks are reported to influence eye blink rate. During this study's interviews, participants reported that the 1PP in the VR game was easier to play than the 3PP. In the task performance, the gunshot count was also bigger in the 1PP than the 3PP. These results suggest that the 1PP was an easy task for the participants to perform. Similarly, previous studies revealed that increased mental workload and task difficulty reduced eye blink rate (Jongkees & Colzato, 2016; Lean & Shan, 2012).

It is empirically known that people tend to close their eyes involuntarily when shooting real guns. In this study, participants may also have closed their eyes when triggering the hand-held controller. Findings showed that gunshot count became higher together with the sessions in both perspectives. This indicates that the participants became skilled in manipulating the hand-held controller. On the contrary, eye blink rate did not change among the sessions; gunshot count had no correlation with eye blink rate. These results suggest that triggering a hand-held controller may not induce eye blink in such VR settings.

Moreover, Slagtera et al. (2015) suggest that learning influences eye-blink rate. However the hit rate of gunshots was not calculated, and eye blink recordings were not performed simultaneously with gunshots made during this VR game. We currently use a VR maze game to address the effect of learning on spontaneous eye blink in VR settings. This type of game does not use any special manipulation of the controller; it is expected to exclude a responsive eye blink.

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Author disclosure statement

The authors have no conflicts of interest to declare.

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