# CONTRIBUTION OF STEREOPSIS AND MOTION PARALLAX TO FEAR RESPONSES IN THE PIT ROOM ENVIRONMENT

*S. Eftekharifar [1,] and Nikolaus. F. Troje [1,2,3]*

[1]Centre for Neuroscience Studies, Queen's University, Kingston, ON, Canada
[2]Department of Psychology, Queen's University
[3]Centre for Vision Research, York University

## ABSTRACT

Virtual reality, in contrast to visual stimulation on computer screens, is characterized by the illusion of presence. Stereopsis and motion parallax are two of the main perceptual factors provided by head mounted displays to create a sense of depth in virtual environments. However, the relative contribution of stereopsis and motion parallax to create the sense of presence is not clear and existing results are somewhat controversial. Here, we study the contribution of stereopsis and motion parallax using the classic pit room paradigm. Participants are required to cross a deep abyss between two platforms on a narrow plank under three experimental conditions. Participants responded to a presence questionnaire after each condition and their electrodermal activity (EDA) was recorded as a measure of stress and anxiety in a threatening situation. The EDA results demonstrated the importance of motion parallax over stereopsis, however, the questionnaire scores were not different among three conditions.

***Index Terms***— Virtual reality, sense of presence, motion parallax, stereopsis.

## 1. INTRODUCTION

Virtual reality (VR) applications are growing at a fast pace. The main goal of VR devices is to provide highly immersive virtual environments in order to create a sense of presence in users. Presence expresses the illusion of being in a space rather than just looking into it as is the case when contemplating a picture. Slater [1] talks about the "place illusion" in that context. A number of depth cues seem to play a role in that respect. While pictorial depth cues such as linear perspective, occlusion, shading, texture gradient, etc. can very well be part of pictures and other projections that do not elicit the sense of presence, stereopsis and motion parallax are generally considered essential parts of virtual environments. Binocular disparities are simulated by presenting two different images to each eye. Motion parallax requires to track the position and orientation of the user's head and use that information in real time to update the rendering of the simulated 3D scene. The information which the visual system derives from motion parallax, while similar in many ways to the information that can be derived from stereopsis, therefore depends on the contingency between active observer movements and the resulting sensory consequences. It has long been hypothesized that sensorimotor contingencies play a major role to establish the sense of presence in the observer [1, 2]. If that is the case, motion parallax would be expected to be more important for the establishment of presence, than stereopsis.

The relative contribution and importance of stereopsis and motion parallax have been investigated in the context of various behavioral tasks. Most of these experiments involved path-tracing tasks. For instance, in some studies, the task for participants was to track a line from a highlighted starting point to find the correct endpoint. The target line was presented among other confusing lines on a 3D display [3, 4]. In other related experiments, the task was to find out if two specific nodes in a complex interconnected graph are connected or not [5, 6, 7, 8]. In most of these experiments, motion parallax was determined to be the more important perceptual quality to affect accuracy [3, 4, 5, 6, 7]. Aygar and colleagues [9] tested the contribution of stereopsis and motion parallax to the perception of structures in 3D point clouds where they asked participants to respond "yes" or "no", depending on whether they observed specific target clusters which were artificially generated in the background pattern. They found that both motion parallax and stereopsis are important to improve accuracy when the frame rate of motion parallax is low, however, when the frame rate increases, motion parallax became the dominant depth cue to detect targets.

In contrast to these studies, there are also others that seem to show that stereopsis is more important than motion parallax, at least for some behavioural tasks. For instance, Hassaine and colleagues [8] used a path tracing task similar to the one used by Ware and colleagues where they found benefits of stereopsis over motion parallax. The importance of stereopsis over motion parallax was also shown by Boustila and colleagues [10]. They placed participants in virtual houses and asked them to orally answer questionnaires about room geometry. Participants also indicated how difficult they found the task. The results showed a main effect of stereopsis on perceived task difficulty and judgments of dimensions of the rooms, that was larger than the main effect of motion parallax. However, no significant effect of stereopsis and motion parallax was observed when participants were asked to rate their subjective sense of presence. There are also other situations where presence or

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absence of motion parallax and stereopsis have no effects on the accuracy of the behavioural performance. For instance, one study [11] reported no effect of these two factors on the performance in a match-to-sample task in which participants had to match a virtual bent wire to three drawings printed on paper. Nevertheless, motion parallax, but not stereopsis, significantly increased presence assessed by a questionnaire. Enhanced subjective presence ratings after introducing motion parallax and stereopsis was also reported by Ijsselsteijn and colleagues [12]. Like in Barfield and Hendrix's [11] study, the effect of motion parallax was considerably larger than the effect of stereopsis.

The inconsistency among the results in various papers might have several reasons. First, different tasks were used among studies. Second, the complexity of the task used in studies can also affect the contribution of stereopsis and motion parallax [13]. However, both of them are important for more difficult tasks. Moreover, according to Naepflin and Menozzi [4] motion parallax is a stronger depth cue when the complexity of the tasks is higher. Third, the quality of stereoscopic viewing can be a reason for the dominance of motion parallax over stereopsis [3]. However, a direct comparison among results is difficult due to the differences among methods, and particularly because the dependent measure is varying widely. To our knowledge, only three studies [10, 11, 12] directly attempted to assess the role of stereopsis and motion parallax for the sense of presence.

The notion of presence has been around for a long time and it is described as the subjective feeling of the sense of "being there" [1, 14]. However, measuring presence in virtual environments is a challenging problem and there has been considerable debate on how to do that properly [15, 16, 17, 18, 19]. Different presence questionnaires were introduced as a subjective measure of presence [20, 21]. Although, participants' conscious feelings and thoughts can be extracted by the questionnaires, these subjective scores apparently fail to give any information about unconscious, somatic responses. Thus, Meehan and colleagues [22] attempted to use other objective metric to measure presence. They hypothesized that: "to the degree that a virtual environment seems real, it would evoke physiological responses similar to those evoked by the corresponding real environment". They used heart rate, electrodermal activity (EDA), and skin temperature as three physiological measures among which EDA and heart rate satisfied their requirements to measure presence.

An interesting experimental scenario to which such measures were applied is the "pit room" paradigm. The first version of this experimental environment was introduced in [20]. The idea of the pit room was inspired by the famous visual cliff experiment introduced by Gibson and Walk [23]. In the version of Meehan and colleagues [22], participants were exposed, in VR, to a situation which would be very scary if it happened in the real world: They had to stand on the ledge of the deep pit while positioning objects at specified locations in the pit room. Even though participants were aware of the simulated nature of the experiment the authors demonstrated that the situation nevertheless elicited severe stress responses, which could be measured in terms of electrodermal activity (EDA) as well as increased heart rate. Slater and colleagues [24] used a similar paradigm to assess the effects of visual realism and the quality of the rendering on the sense of presence.

The goal of the current experiment was to assess the relative contributions of stereopsis and motion parallax to the sense of presence in a virtual environment. We focused on these two cues because they are among the most prominent depth cues and provide similar information about shape and depth, on the one hand. However, on the other hand, they play very different roles in the context of O'Regan and Noë's [2] theory of sensorimotor contingencies, which we consider, along with Slater [1], central to the understanding of the sense of presence. If sensorimotor contingencies play a major role in the establishment of the "place illusion" then the lack of motion parallax is expected to impact the sense of presence much more than a situation that compromises stereopsis.

Similar to the work discussed above, we aimed for a paradigm that provides means to measure the sense of presence both explicitly with a questionnaire, but also with physiological measures and therefore more objective means. For the questionnaire, we adopted the one used by Slater and colleagues [24] in a similar experimental paradigm. In addition, we recorded participants' electrodermal activity. Using these measures, we tested three conditions during which either both stereopsis and motion parallax were provided, or the use of either stereopsis or motion parallax was compromised.

## 2. METHODS

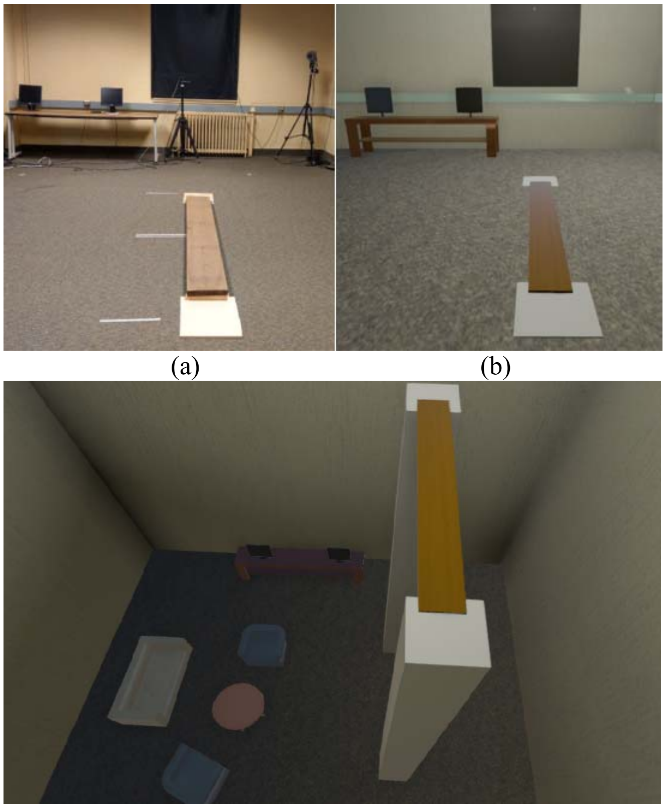
### 2.1. Participants

Twenty-six participants (14 females and 12 males) with an age between 19 and 30 years were recruited for this study. All participants had normal or corrected-to-normal vision. Two of the participants withdrew from the study. The statistical analysis was performed on the remaining 24 participants. The experiment was approved by the Human Ethics Committee of Queen's University and participants were compensated with $5 for their participation.

### 2.2. Apparatus and stimuli

The virtual environment was designed in Unity3D and presented by means of an HTC VIVE head-mounted display (HMD) with a resolution of 1080×1200 pixels per eye and a refresh rate of 90 fps. An MSI backpack computer with Intel Core i7 CPU, 16 GB of RAM and a NVIDIA 1070 GTX graphic card was used and the experiment was implemented with Unity3D.

The virtual environment was modeled after the real laboratory space. That room was about 12×10 m large, contained a support pillar on one side and windows on two sides. The real space also contained two small platforms



(a) (b)

(c)

**Fig. 1.** Real (a) and virtual (b) environments. Pit room environment after the floor was dropped by 8 meters (c).

which were placed flat on the ground. They were connected by a heavy wooden plank which was 2.5 meters long, 28 cm wide and 5 cm thick. Upon entering the virtual reality, participants saw the same layout of the room with the same objects and furniture. It also included the two platforms and the connecting plank (Fig. 1 a, b). Note that the edges of the real plank and its ability to slightly bend between the two support platforms provided realistic tactile/haptic feedback.

Initially, there was no "pit" in the room. Later into the experiment, the floor of the room was dropped by 8 m while the platforms and plank remained at their locations now high above the dropped floor (Fig. 1c).

We used a virtual humanoid avatar to represent the participant's body, with the intention to increase immersiveness in VR. Seeing where participants placed their feet also made them more confident and allowed them to move more natural on the plank. Participants could see "their" arms and lower body and particularly their feet. Their movements were captured by tracking 12 markers (three on each hand and foot) using 15 real-time Qualisys motion capture (MOCAP) cameras at a sampling rate of 120 Hz. We used the Final-IK (Rootmotion Inc.) inverse kinematics plugin for Unity3D to predict the movement of other joints of the body.

Participant's electrodermal activity was recorded using an E4 wristband (Empatica Inc.) with sampling frequency of 4 Hz.

### 2.3. Design

The experiment employed a within-subject design in which each participant experienced three conditions. It was run in one session which lasted approximately half an hour. The order of the three main conditions was counterbalanced among participants. The conditions were:

(1) Participants experienced the pit room situation under standard VR conditions, that is, with both stereopsis and motion parallax functioning normally;

(2) Motion parallax was compromised. While changes in orientation as well as linear fore-aft and vertical movements resulted in image changes that simulated normal motion parallax, lateral movement of the participants' head did not affect the rendering on the displays of the HMD. Stereopsis was rendered as in condition (1);

(3) Stereopsis was compromised. Rather than providing dichoptic images to the two eyes, both eyes were presented with the same image taken from a single "cyclopean" camera viewpoint. Motion parallax was implemented as in (1).

### 2.4. Task and procedure

The task and experimental procedure were explained to each participant before starting the experiment. We gave a disclaimer to each of the participants informing them that they were free to withdraw from the experiment whenever they feel uncomfortable. We then equipped each participant with the E4 wrist band and the HMD device and attached markers to their feet and hands. When participants entered the virtual environment, they were instructed to stand at the center of the first platform. We asked them to relax and get familiar with the environment. Then we started recording their baseline electrodermal activity. After one minute, the floor of the room smoothly moved down by eight meters. The participants were then asked to start walking on the plank and to cross the abyss to reach the other platform and then come back to the original position. After completing the task, they took off the HMD and began to answer the presence questionnaire. Upon completion, they put on the HMD again and experienced another condition followed by the same presence questionnaire used in the previous condition. This procedure was repeated once more for the last condition.

### 2.5. Measurements

The dependent measures included participant's electrodermal activity (EDA) and subjective rating of presence. The presence questionnaire was the one introduced by Slater and colleagues [24]. It consisted of 11 questions related to presence. Participants responded to each question on a 7-point Likert scale where the number they chose showed the level of agreement with the corresponding statement. As the objective measure of presence, we used participants' EDA recordings in the baseline and pit room environment. We recorded EDA during one-minute base-line and then for the rest of the experiment. From the raw data, we derived ΔEDA as a measure of change in skin conductance between base-line and the pit room environment;

$$\Delta EDA = \text{mean EDA}_{\text{Pit room}} - \text{mean EDA}_{\text{Baseline}}. \quad (1)$$

## 3. RESULTS

Data from 24 participants were analyzed. Fig. 2 illustrates differences between the three different conditions. A two-way repeated measures ANOVA (condition × order) revealed a main effect of condition $F[2,54] = 6.71$; $p<0.005$. Bonferroni-corrected t-test show a significant difference between the condition without motion parallax and the two other conditions, however, no significant difference was observed between normal and no-stereo conditions, which means that eliminating stereopsis does not have any effect on participants in terms of fear response. However, the results demonstrate the importance of motion parallax over stereopsis for eliciting an EDA response and thus confirm our hypothesis about the dominance of motion parallax.

We did not observe a significant main effect of the order of exposure $F[5,54]=2.34$; $p=0.054$ , nor was the interaction between conditions significant $F[10,54]=0.45$; $p=0.91$.

We also calculated the mean score of the questionnaires for each condition. Fig. 3 shows the results of the presence questionnaire. There was no significant difference in terms of subjective feeling of presence among the conditions $F[2,54]=0.04$; $p=0.95$. These results go against our expectation. We expected lower presence scores in no-stereo and no-parallax conditions however, all scores are very similar to each other. A 2-factor (condition × question) repeated-measures ANOVA on the scores did not reveal a significant interaction. Visual inspection of the means also did not imply that specific effects on particular questions cancelled each other out in the summary statistics.

## 4. DISCUSSION

In this paper, using the pit room paradigm, we measured the relative effects of motion parallax and stereopsis on two different measures that have become established for the assessment of the sense of presence in virtual environments. The first one is a questionnaire that has been developed specifically for the pit room environment [24]. The second is the electrodermal skin response which probably only applies to situations that contain stressful or emotionally loaded situations. Elevated arousal increases the activity of sweat glands which translates into elevated EDA.

Results showed that eliminating stereopsis does not have any effect on EDA response compared to the normal condition where participants had both motion parallax and stereopsis. However, eliminating motion parallax strongly enhanced EDA response compared to the other two conditions. In a way, we found what we expected: Compromising motion parallax has much more of an effect

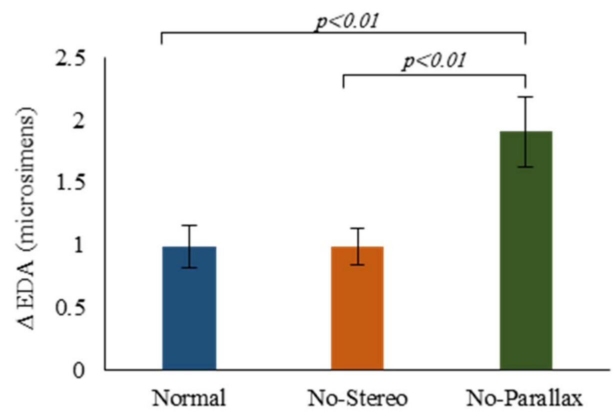



**Fig. 2.** ΔEDA for normal, no-stereo and no-parallax conditions. Error bars represent SEM.

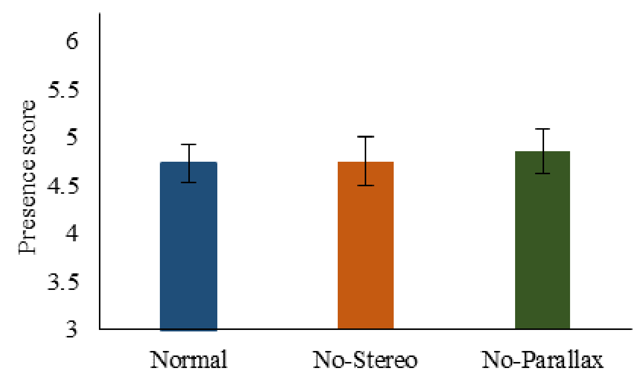



**Fig. 3.** Presence score for normal, no-stereo and no-parallax conditions. Error bars represent SEM.

than eliminating stereopsis. On the other hand, however, we did predict an effect with the opposite sign: If tampering with motion parallax breaks the place illusion and impacts the sense of presence, we would expect participants to feel less fear of the abyss in the virtual pit room. Consequently, the EDA response should be lower, not higher.

An explanation for this unexpected result might be that in a potentially fearful situation like the pit room situation, when an essential depth cue is missing, participants face a new condition which is less naturalistic compared to the real world but nevertheless more stressful. In fact, some participants explicitly reported to find themselves in a strange environment which was new and scarier to them after experiencing the condition without lateral motion parallax. They found themselves in a potentially dangerous situation in which their health seemed to depend on staying upright and balanced on the narrow plank. The situation apparently became even more dangerous in the no-parallax condition because they were now lacking an important sensory cue that helped them to maintain their balance. The fact that we observed this behavior only in the no-parallax condition but not in the no-stereo condition is perfectly in line with our hypothesis where motion parallax is a more important depth cue than stereopsis for the sense of presence.

The questionnaire results were surprisingly flat. We expected less subjective feeling of presence when important depth cues are not available as reported in [11, 12]. We can only speculate why this was the case. First, high quality VR devices are still novel and unfamiliar to most people and that was also true for the majority of our participants. The new experience might have been so exciting that they were not consciously differentiating between normal and a less normal conditions. Second, the nature of the experiment was so stressful for most of the participants that they mostly focused on safely crossing the plank and completing the walking task that they were not able to differentiate between the conditions in terms of presence.

Meehan and colleagues [22] claim that physiological responses such as heart rate and skin conductance can be considered as objective metrics of presence in stressful situations: A greater physiological response means a higher sense of presence. This claim is only partly confirmed by our results. In our experiment, eliminating motion parallax leads to strongly enhanced EDA response however, subjective feeling of presence did not change at all in no-parallax condition compared to the two other conditions. Thereby, a greater physiological response does not necessarily mean a higher sense of presence according to the questionnaire -- even in a stressful virtual environment.

In conclusion, the results from this study suggest that for stressful situations, motion parallax is a more efficient depth cue than stereopsis in terms of fear response which was measured by EDA. The relation between this response and perceived presence is not clear, however. Our experiment provides an example in which increased EDA is obviously not coupled with an increased sense of presence. Explicit ratings in terms of the presence questionnaire do not change, and the manipulation that resulted in the increased EDA response is a manipulation that is expected to break presence rather than enhance it.

## 5. ACKNOWLEDGEMENT

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