# The Effect of Motion Parallax and Binocular Stereopsis on Visual Comfort and Size Perception in Virtual Reality

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**Abstract.** The perceptions of comfort and presence in virtual reality (VR) are tightly linked to the richness of the visual cues that are made available to the viewer and the fidelity with which they are rendered. In this work, we present two subjective studies, the first of which is aimed at understanding how the quality of experience in VR is affected by the presence and absence of motion parallax and binocular stereopsis. The second one reports an illusion where, in the absence of stereo disparity, objects are perceived to be significantly larger compared to when the stereo cue is available, with the average magnification being as high as 2x for objects up-close. We conclude that while rendering the correct motion parallax is critical for mitigating visual discomfort, the viewers' ability of accurate size perception is largely dependent on binocular stereopsis.

**Keywords:** virtual reality, size perception, motion parallax, stereopsis

## 1 Introduction

The quality of a virtual reality (VR) experience goes hand-in-hand with the faithful reproduction of numerous visual cues. Conflicting cues have long been known to cause discomfort, fatigue, and nausea. The most common examples are vergence-accommodation conflict [1] and visual-vestibular conflict [2][3]. Similarly, binocular vision and motion parallax have been identified as prominent depth indicators [4], in the absence of which the virtual scene appears lacking a compelling 3D perception. In this work, we present two subjective studies, each focused on a vital aspect of the quality of experience in VR. They look at the effect of parallax and stereo vision on visual comfort and size perception in the virtual environment.

## 2 Related Work

Researchers have studied the discomfort caused due to visual-vestibular conflict [3] using apparatus such as flight simulators [2], fish-tank VR [5] and stereo displays. The user experience in modern head-mounted displays is drastically different and there is a lack of similar large-scale, systematic studies looking at the effect of depth cues on VR sickness. This work aims to take a small step towards bridging that gap. Similarly, size and depth perception and their interplay have been well-documented in psychology literature. However, all these studies were conducted using either stereoscopic displays [6] which lack motion parallax and immersion, or using perspective images [7] which further also lack stereo, or with a real-world

setup [8] which lacks the flexibility of smoothly manipulating object sizes and distances. In this work, we use the power of modern VR to design a size perception study that offers flexibility and can test the effects of motion parallax and binocular stereopsis both together and individually in an immersive environment.

## 3 Visual Comfort

The goal of this study is to observe the effect of presence and absence of motion parallax and stereo vision on the perceived quality of experience (QoE) of a sedentary viewer in VR. To that end, we constructed 2 virtual scenes with several floating cubes and a skybox at infinity. Scene 1 had the cubes distributed between 1 and 4 meters, while Scene 2 had them between 4 and 16 meters. The two scenes had 17 and 19 participants, respectively. In each case, the participants were shown 30 pairs of stimuli, where each stimulus was the virtual scene rendered using one of the 6 settings – {mono, stereo} rendering × {no parallax (conventional), only horizontal parallax (vertical head-motion is ignored), full-parallax (6-DoF)}. For each stimulus pair, the participants were instructed to rate their QoE on a scale of (-3 to +3) using Comparison Category Rating [9]. Fig. 1 summarizes the findings of the study. Each bar shows the mean opinion score of one setting against all other render settings. The "0" mark is thus arbitrary and only the relative heights of the bars should be used to draw inferences.

1. In the presence of motion parallax, also providing stereo leads to a big boost in the QoE, whereas providing stereo in the absence of motion parallax does not lead to a statistically significant change.
2. For scenes with close-by objects (Scene 1), motion parallax seems to be the biggest factor that governs the overall quality, whereas, for scenes with faraway objects (Scene 2), both motion parallax and stereo are equally effective.
3. Finally, as expected, the 6 settings show a much larger variation in QoE for scenes with objects up close (Scene 1 vs Scene 2).

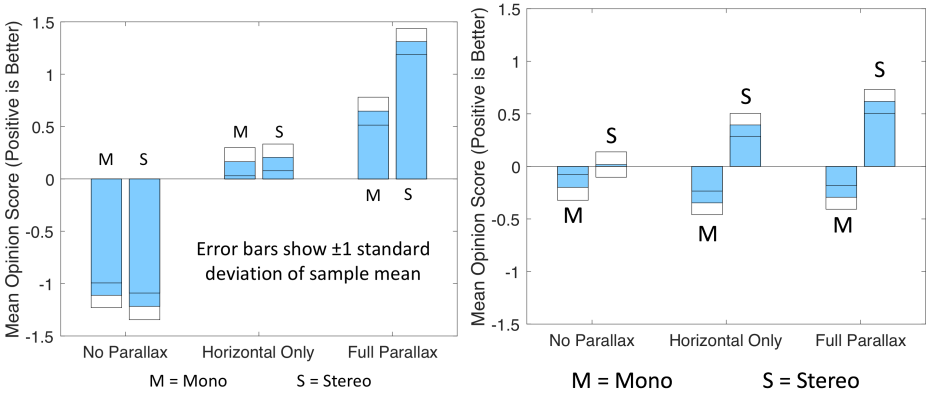


**Fig. 1.** In each graph, the Y axis gives the mean opinion score (higher is better) and the bars give the 6 different render settings, as indicated. Left: Scene1, right: Scene 2

## 4 Size Perception

While conducting the visual comfort study, we came across a peculiar effect – in the absence of stereo disparity, scene objects close to the viewer were perceived to be disproportionately magnified. Upon further investigation, we observed that the illusion was sustained across a range of photorealistic scenes and decided to conduct the following study to quantify it. This subjective test is aimed at studying the roles that motion parallax and binocular disparity play in size perception. During each stimulus, every participant was shown 2 disc objects placed at equal distances facing the viewer, one rendered stereoscopic and the other monoscopic (same content to both eyes). The viewers were then asked to adjust the size of the monoscopic object until the two objects had the same apparent angular size (as opposed to the apparent absolute size), defined in [10]. We tested 13 distances spaced uniformly in $(0, 4]$ Diopters, 4 angular sizes (object diameter $\sim$ 5, 7, 10, and 14 degrees), and the motion parallax was toggled on/off, together giving 104 stimuli per user. The stimuli were spread across 4 different scenes – 3 scenes had a ground plane, one had architecture with some perspective; one had a bright skybox while the others had a dark background. The results over 18 participants are summarized in Fig. 2. We observe an illusion where monoscopic objects are perceived to occupy a larger angular size compared to their stereo counterparts. The ratio of the two object sizes picked by the viewer will be called "illusion magnitude" (1 corresponding to no illusion). We find that

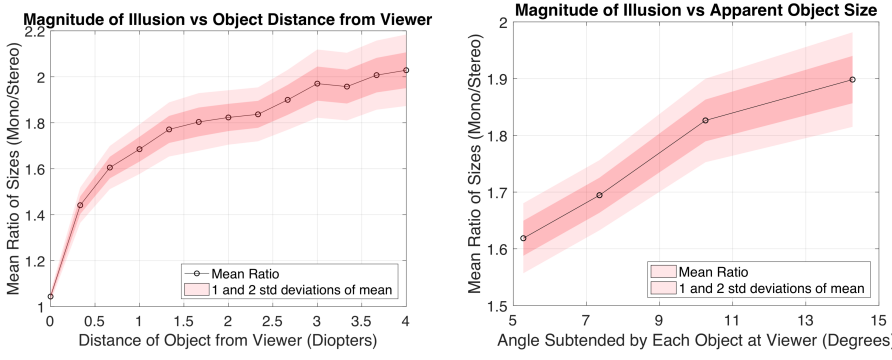


**Fig. 2.** Both graphs have illusion magnitude on the Y axis. The X axis shows the distance of the objects from the viewer in Diopters (left) and the angular size of the objects (right).

1. Illusion magnitude rises as distance to objects falls (Fig. 2, left). Lack of disparity makes the monoscopic object appear distant and overestimation of size with increasing distance is well-known [6][8][7].
2. The illusion is stronger for objects with larger angular size (Fig. 2, right). This could be because for a given distance, larger stereo objects appear farther [6] and this reduces the depth discrepancy between the stereo object and the perceptually distant mono object and thus reduces the illusion.
3. While all participants share these trends, we find a large individual variation in the magnitude of the illusion (ranging from illusion magnitudes of close to 1 to over 4, for objects at 25 cm). This could be due to individual differences in stereo acuity and eye dominance and needs to be investigated further.

4. We find that the illusion magnitude shows no statistical trend across different scenes or, more surprisingly, in the presence or absence of motion parallax.

## 5 Discussion and Future Work

Possible future work could be to extend the visual comfort study to dynamic scenes. Also, the results reported in the study hold only for passive viewing conditions and may change if the participants are asked to perform a specific task. Conducting a user study and measuring the stereo acuity and the eye dominance of the participants following [11] might help shed light on the dependence of the illusion magnitude on the angular object size. The work in [12] may provide a useful framework to develop a theoretical model explaining the size illusion.

## 6 Conclusions

In this work, we presented two subjective studies aimed at understanding the role of motion parallax and binocular stereopsis on the overall quality of experience (QoE) and on size perception in virtual reality. We found that motion parallax is the most important factor governing QoE, especially for scenes with objects up close. Providing stereo vision leads to a boost in QoE when motion parallax is already present but does not lead to a significant change when parallax is absent. From the size perception study, we found that an object rendered monoscopic is perceived to occupy a larger angular size than if the same object is rendered in stereo, with the effect getting stronger as the object gets closer. For a distance of 25 cm from the viewer, the monoscopic object is perceived on an average 2x the size of the stereo object (over 4x for some participants). This could be explained by the dependence of perceived size on the perceived distance.

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