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3D Field of View: Effects of Immersive VR on Visual Perception and Experience

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Distance and Depth Perception in VR

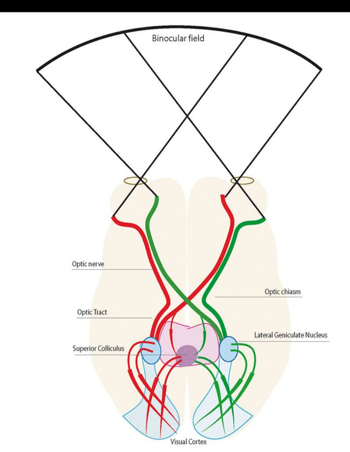
Virtual Reality (VR) research has produced a substantial amount of evidence showing that humans significantly underestimate distances in Virtual Environments (VEs; Creem-Regehr et al. 2013; Messing & Durgin, 2015). One suggested contributing factor to this trend is the mechanical properties of VR equipment, such as restricted field of view (FOV).

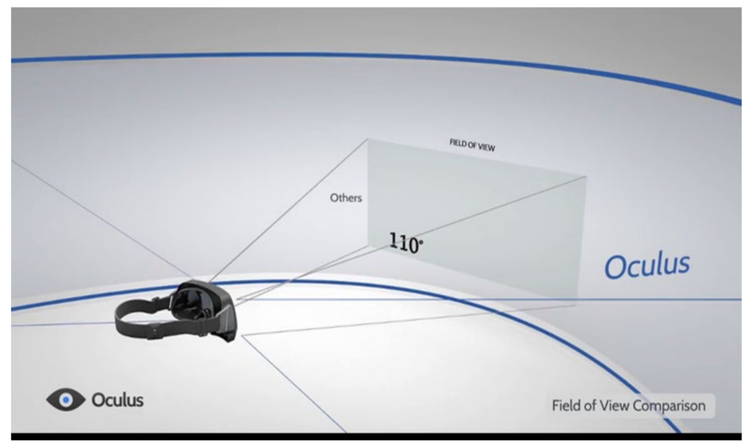
The literature suggests that when performing visually guided actions with a head-mounted display (HMD), users often underestimate distances in a VE and tend to interact within the virtual space as if it is smaller than the actual geometric parameters of the VE model. Therefore, it is likewise suggested that providing users the ability to move their head to explore the VE prior to performing a perceptual task allows them to familiarize and recalibrate their physical movements to match the perceptual scale in a VE.

This poster presents preliminary findings of a baseline assessment that compare perceptual accuracies between a large 65-inch screen-based VR display (SBD) and a current HMD model, the Oculus Rift. In this exploratory study, the authors theorize that while restricted FOV might reduce or interfere with the visual information needed to accurately scale space, HMDs can provide a robust and effective way to interact with virtual spaces.

Field of View

The human visual system has a natural FOV of 180° (**Figure 1**, right; Messing & Durgin, 2015). Humans' FOV is divided into central and peripheral vision, with each eye having a horizontal FOV of 150°. The overlap region (binocular FOV) in the central fovea averages 120° FOV, with a range of 30°- 35° peripheral vision for each eye, thus making the combined horizontal FOV 180°.





Current VR HMDs seldom go beyond 110°, limiting visual information to the periphery. This restriction can influence the way users perceive factors within their environment. Specifically, perceptual inaccuracies frequently occur while estimating the depth, distance, and slope of objects in a VE. (**Figure 2**, left; Oculus, 2018)

Mechanical Properties of HMDs

Current HMD designs consist of stereoscopic liquid crystal displays (LCD) or organic light-emitting diode (OLED) displays and lenses that project to both the central and peripheral vision of the eyes. These are housed in a wearable format that allows for free physical movement and interaction with immersive virtual environments. Displays within the headset have greatly enhanced in resolution and, along with new lens designs, they have allowed for accurate replication of real world conditions.

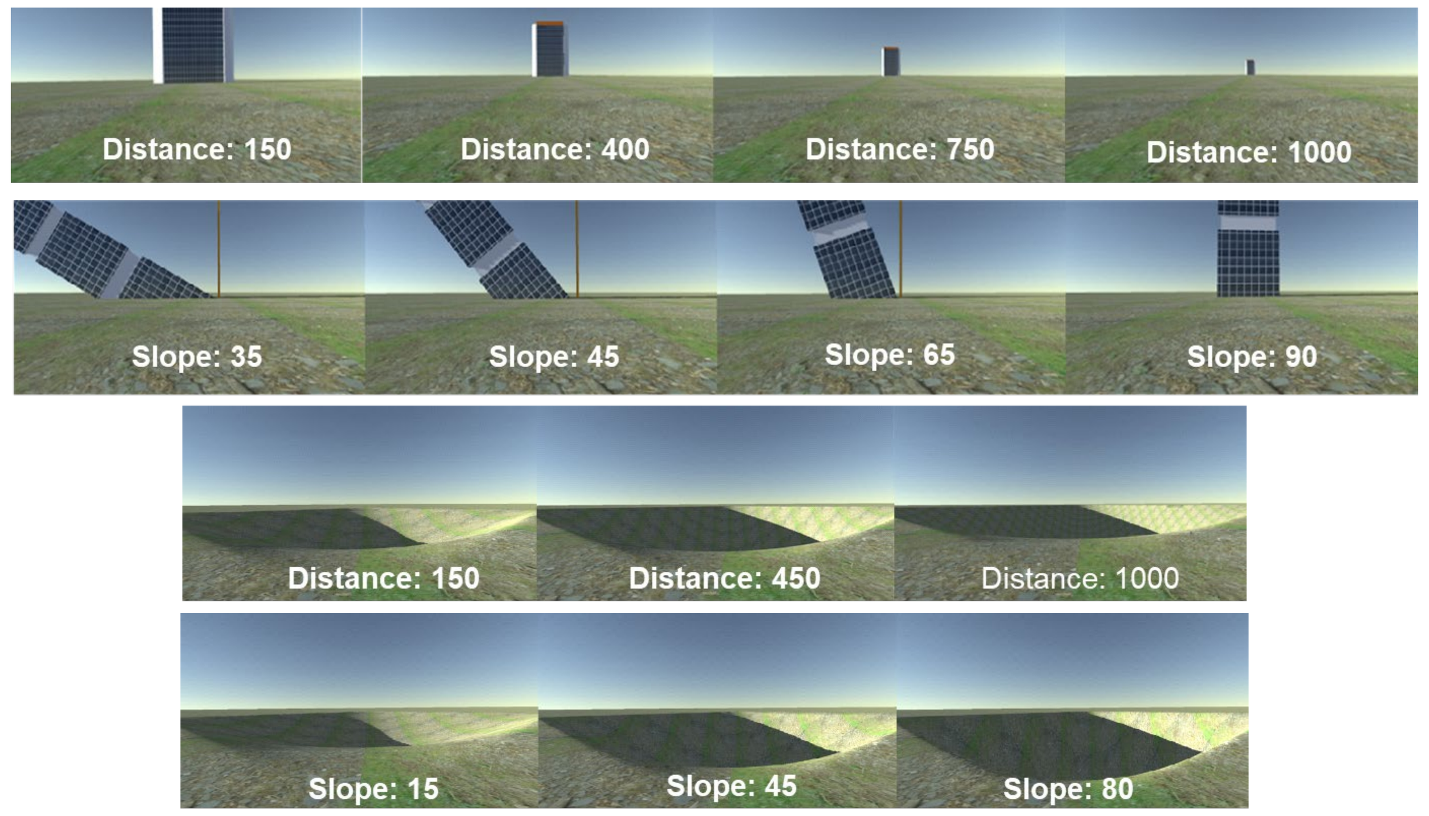
Depending on the system, displays can have resolutions of 640 x 800 to 2160 x 1200. HMDs employ a stereoscopic design with varying lens types that allow for sharper image quality and greater depth perception. HMD systems range in weight between 400-1300 g and range in diagonal FOV between 60-110°. Weight, lens type, and limited FOV are all possible contributing factors to the underestimation of distances in virtual environments (Buck et al. 2018). Current VR HMDs seldom go beyond 110°, limiting visual information to the periphery. This restriction can influence the way users perceive factors within their environment. Specifically, perceptual inaccuracies frequently occur while estimating the depth, distance, and slope of objects in a VE.

Experimental Design

In this experiment, 54 CUA undergraduates participated in this study (n_{male}= 27, n_{female} = 28) with a mean age of 19.6 years. Participants were randomly assigned to one of two condition orders (HMD and SBD) in two phases of the within-subjects baseline assessment.

- **Phase 1:** Participants were shown a series of buildings and craters and were told the distances and slopes of each. The upward slope condition used a 90° reference angle. This reference angle was not present in Phase 2.
- **Phase 2:** Participants were shown a random series of buildings and craters and asked to estimate their distances and slopes to the nearest 5/10 feet for distance and 5/10 degrees for slope. Stimuli shown in Phase 2 differed from those values presented in Phase 1.

Presented Baseline Stimuli



Estimation Techniques

Buildings: Participants estimate distance across a ground plane to the base of the target object.

Craters: Participants estimate the distance to the farthest point of craters requiring their perception of topographical changes in depth to the ground plane.

Results

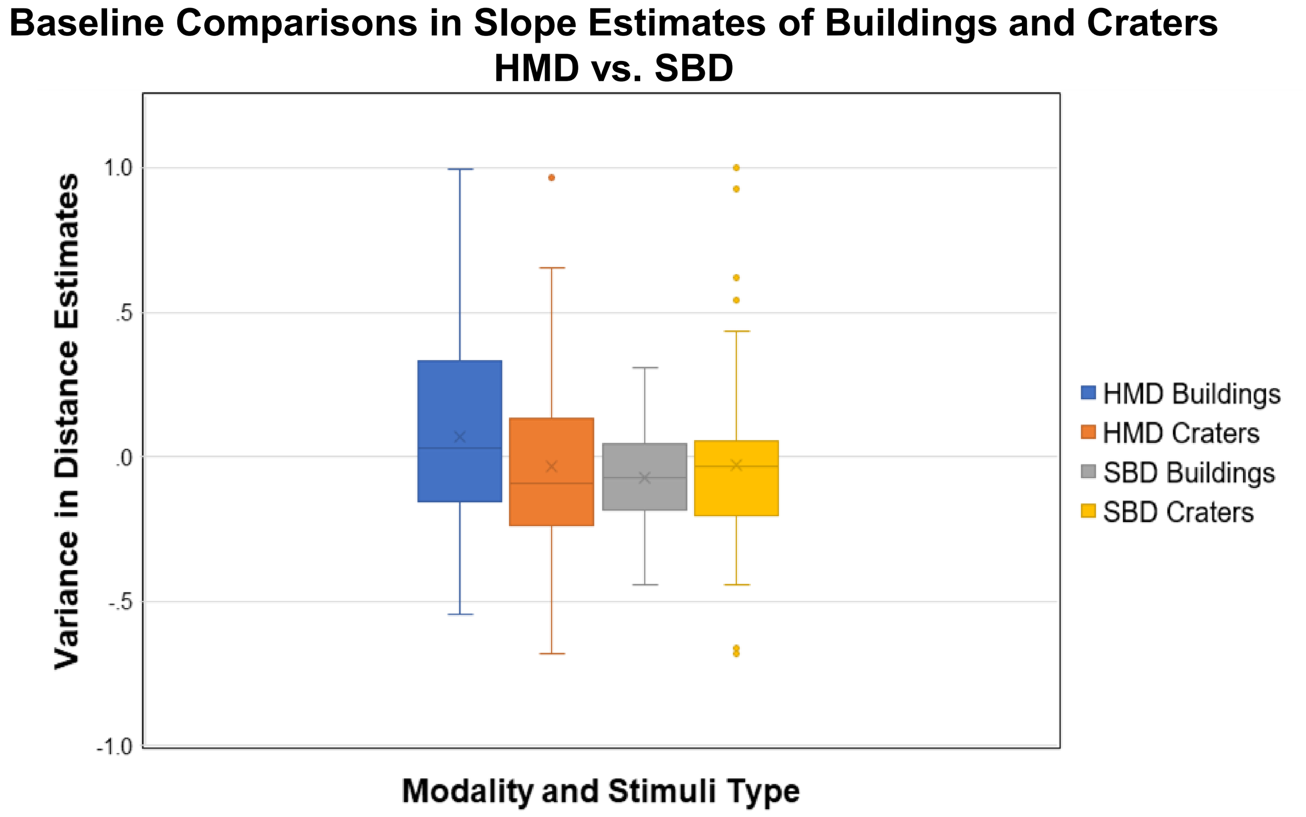


Figure 3. Variance in baseline estimates for building and crater distances.

A 2 (modality) x 2 (stimuli type) repeated measures ANOVA revealed a significant main effect of modality on estimates of distance for buildings $F(1,53) = 12.18$, $p<.001$. Underestimation of distances by 7% with SBD and overestimation by 7% with HMD. Estimates of crater distances were not significantly different between SBD and HMD $F(1,53)= .005$, $p=.944$.

Results Cont'd

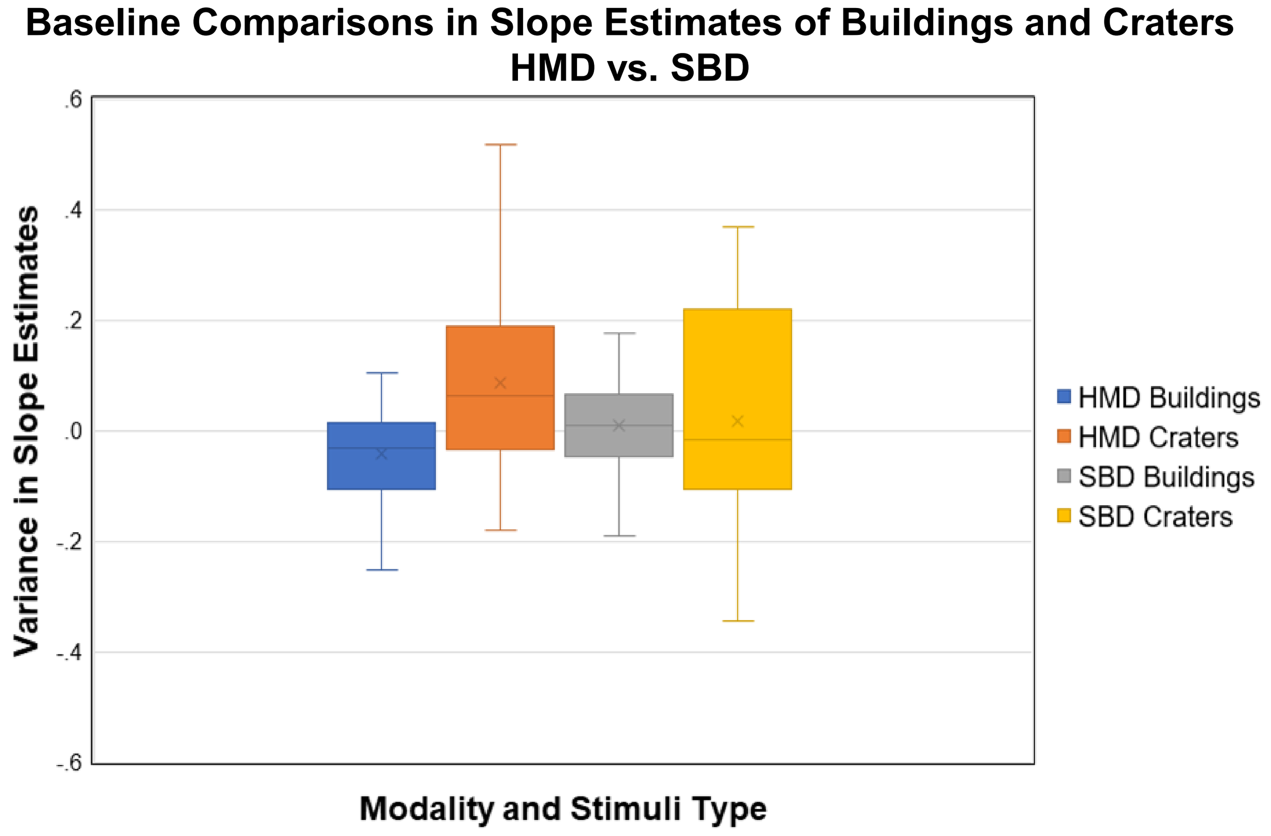


Figure 4. Variance in baseline estimates for building and crater slopes.

Modality had a significant main effect on slope estimates for buildings $F(1,53)=9.72$, $p<.05$ and craters $F(1,53)= 4.95$, $p<.05$. Underestimation of upward slopes of buildings by 4% with HMD and only 0.9% with SBD. Overestimation of downward slopes of craters by 2% with SBD and by 9% with HMD.

Concentration: There was a main effect of modality on perceived ability to concentrate in the environment, $F(1,53)= 8.12$, $p<.05$, $\eta 2=.80$. Participants reported being able to concentrate more on the assigned task with the SBD (M=2.93, SD=1.03) than with the HMD (M=2.39, SD=1.27).

Perception of Natural Movement: There was a main effect of modality on perception of movement in the environment $F(1,53)= 12.81$, $p<.001$. $\eta 2= .20$. Participants reported their movement felt more natural with the SBD (M=3.98, SD=.74) than with the HMD (M=3.35, SD=1.12).

Awareness of Real Environment: There was a main effect of modality on perception of awareness in the environment, $F(1,53)=4.90$, $p<.05$. $\eta 2=.09$. Participants reporting being less aware of their real environment with the HMD (M=3.35, SD=.1.14) than with SBD (M=3.24, SD=.15).

Discussion

The results of this study indicate that while there was no significant difference between HMD and SBD modalities in participants' ability to estimate crater distance, there were significant differences between HMD and SBD modalities in participants' ability to estimate distance and slope for buildings as well as slope for craters.

These findings also suggest that a wider FOV contributes to improved performance on distance and slope judgement tasks with a specified target (building) on a level ground plane and on directional slope judgement for a ground plane with topographical changes in depth (crater). The increased variance in participant estimation in the HMD condition might be attributable to a reduced sense of awareness of one's surroundings and lack of spatial familiarity/recalibration in the VE as seen in several studies reviewed by Renner and colleagues (2013).

The data collected and analyzed in this study represent a preliminary baseline that can be used to assess and correct for the wide range of estimate variance found in the initial experimental conditions of this study. The authors propose that due to the physical edges of the SBD, building slope estimates aligned with the vertical plane of the screen are much more accurate than other judgements due to the visible reference angles.

It is notable that despite the overwhelming convergence of literature suggesting individuals underestimate distance and slope in HMDs, participants in this study overestimated distance in the building condition and overestimated slope in the crater condition. This might be the result of distance judgement priming and practice immediately preceding the baseline trials in phase 1 of the protocol, which makes these directional trends vital to controlling for the variance observed in participant estimate values, but future research should examine this trend more rigorously.