Estimation of Detection Thresholds for Audiovisual Rotation Gains

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ABSTRACT

Redirection techniques allow users to explore large virtual environments on foot while remaining within a limited physical space. However, research has primarily focused on redirection through manipulation of the visuals used to represent the virtual environment. We describe a within-subjects study (n=31) exploring if participants' ability to detect differences between real and virtual rotations is influenced by the addition of sound that is spatially aligned with its virtual source. The results revealed similar detection thresholds for conditions involving moving audio, static audio, and no audio. This may be viewed as an indication of visual dominance during scenarios such as the one used for the current study.

Index Terms: H.1.2 [Information Systems]: User/Machine Systems—Human factors; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality;

1 INTRODUCTION

Real walking in virtual environments offers demonstrable advantages over other common locomotion techniques, including but not limited to, the sense of presence [8], navigation performance [7], and benefits for attention and memory [6] [9]. Ideally, the walker's virtual movement should only be constrained by the simulated architecture and topography. However, because virtual environments often are larger than the physical interaction space, real-world constraints are likely to impede on the walker's freedom to move. *Redirection techniques* allow users to navigate virtual environments on foot in a physical area of limited size by subtly or overtly manipulating walker's path through the environment (for an overview of different redirection techniques see [5]). One subtle approach to redirecting walkers, is to apply imperceptible translation, curvature, and rotation gains to the movement of the virtual camera and thereby scale and bend the walker's path, as well as increasing or decreasing the virtual rotation resulting from physical rotation. Several studies have explored redirection through visual gains, but research on the influence of audition is scarce. Serafin et al. [3] performed two studies demonstrating that acoustic rotation and curvature gains can be used to redirect blindfolded users. While these results are interesting, there is only a limited number of meaningful scenarios and applications involving virtual environments devoid of visual stimulation. Moreover, the results do not reveal whether the addition of spatialized audio to a graphical environment will influence the amount of manipulation that can be performed without the walker noticing it. The current poster details a study exploring if participants' ability to detect differences between real and virtual rotations (i.e., rotation gains) is influenced by the addition of sound that is spatially aligned with its virtual source.

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2 METHOD AND MATERIALS

A total of 31 participants (25 males and 6 females), between the ages of 19-37 (M=26.4, SD=4.5) took part in the study. The participants comprised university students and staff, and all reported having normal or corrected-to-normal hearing and vision. The study relied on a within-subjects design and compared three conditions that varied in terms of the provided auditory feedback: *no audio* (only visuals were displayed), *static audio* (the sound was spatialized, but unaffected by the applied gain), and *moving audio* (the sound was spatialized and aligned with the virtual source during redirection). The condition involving static sound was included in order determine if potentially observed effects were merely caused by the presence of sound, rather than audiovisual redirection. In order to explore if the thresholds for detecting rotation gains varied across the three conditions, we adopted the method employed by Steinicke, Bruder and Jerald [4]; i.e., the method of constant stimuli in a two-alternative forced-choice (2AFC) task. Particularly, the subjects were asked to perform a series of rotations on the spot and for each trial judge if the virtual rotation was larger or smaller than the physical rotation. In the beginning of each trial the virtual environment was shown on the HMD along with a sign displaying an arrow indicating whether the participants should turn to the left or right. The participants were instructed to turn until they were facing a red dot located at eye height. All trials involved a physical rotation of 90°, and the participants were exposed to rotation gains ranging from 0.5 to 1.5 in increments of 0.1. Each gain was repeated 5 times yielding a total of 165 trials (55 per condition) which were presented in randomized order. After completing all trials the participants were asked to fill out a questionnaire related to their general experience of the virtual environment and the auditory feedback. Finally, simulator sickness was measured using the Kennedy-Lane Simulator Sickness Questionnaire (SSQ) which was administered immediately before the first and after the last trial [2]. The graphical environment (Figure 1) comprised a bridge crossing a stream surrounded by trees and was generated using Unity 3D and presented using an nVisor SX60 head-mounted display. The auditory stimuli comprised the sound of a waterfall, spatialized using Vector Base Amplitude Panning, implemented in Max/MSP, and delivered using a 16-channel surround sound system. The 16 speakers (Dynaudio Bm5A mk II active monitors) were evenly distributed at ear height along the circumference of circle with a diameter of 7 meters. The participants were placed at the center of this circle and their head-movement tracked using a 16-camera Optitrack motion capture system.

Figure 1: Screenshots from the participants' perspective: beginning of a trial (left), arrow signifying the turning direction (middle), and red dot indicating to the participants that they should stop turning (right).

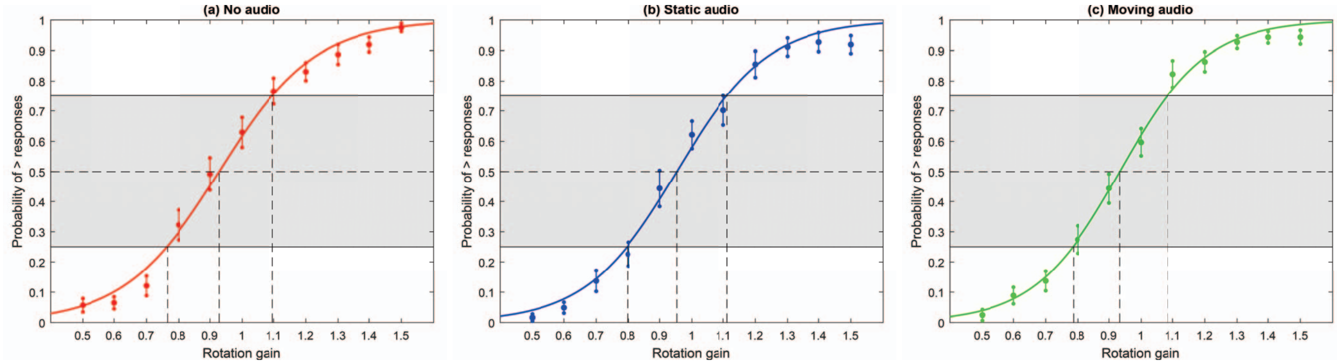

Figure 2: Pooled results of the discrimination between virtual and physical rotation for: (a) no audio, (b) static audio, and (c) moving audio. The x-axes represent the applied rotation gains and the y-axes shows the probability of judging the virtual rotation to be larger than the physical one.

3 Results

Figure 2 illustrates the results obtained from the three conditions; i.e., the mean detection thresholds and the standard error across all participants for the applied gains. Particularly, the x-axes represent the applied rotation gains, and the y-axes represent the probability of the participants judging the virtual rotation to be larger than its physical counterpart. The solid lines represent the fitted psychometric function with the form $f = \frac{1}{1+e^{ax+b}}$ where a and b are real numbers. For each of the three psychometric functions the point of subjective equality (PSE) was derived; i.e., the point at which the participants seemingly could not differentiate between the virtual and physical rotation since they responded "faster than" in half of the trials. Detection thresholds for gains smaller than the PSE (D_{low}) were defined as the points at which the participants responded "faster than" in 25% of the trials, and the detection thresholds for gains higher than PSE (D_{high}) were similarly defined as the points at which the participants responded "faster than" in 75% of the trials. The PSE and detection thresholds of the three conditions were as follows: no audio ($PSE = 0.93$, $D_{low} = 0.77$, and $D_{high} = 1.10$), static audio ($PSE = 0.95$, $D_{low} = 0.80$, and $D_{high} = 1.11$), and moving audio ($PSE = 0.93$, $D_{low} = 0.79$, and $D_{high} = 1.08$). When asked to rate how useful they had found the moving audio the participants ratings were distributed as follows: 17 "not useful at all", 16 "somewhat useful", 1 "useful", and 1 "very useful". Finally, comparison by means of a paired-sample two-tailed t-test revealed a significant difference between the overall simulator sickness scores obtained before and after exposure to the virtual environment ($t(29) = -5.06$, $p < 0.01$). Note that one participant failed to complete the SSQ.

4 Conclusion

The most notable finding of the current study is arguably the similarity between the three conditions in regards to the PSE and the associated detection thresholds. Existing work on redirection techniques have demonstrated that visual information to a large extent can dominate proprioception and vestibular cues during this type of discrimination task. The findings presented here may be viewed as an indication that the relative influence of audition is minimal during scenarios such as the one used for the current study. A likely explanation is that vision generally is considered superior to audition when it comes to estimations of spatial locations of objects [1]. The participants self-reports similarly suggested that less than half of the participants considered the sound useful. Notably, several participants remarked that they did not feel that they could rely on the sound because it was behaving inconsistently across trials. Considering that the order of all 165 trials was randomized, it seems likely that the condition involving static sound may be to blame. Moreover, it is interesting that even though few participants found the sound useful with respect to the discrimination task, several viewed it as contributing positively to their experience; e.g., when asked open-ended questions about their experience, participants made comments such as "it was more immersive", "it felt more real", and "the sounds made me feel more present in the environment". It should be stressed that the current study cannot unequivocally rule out that spatial audio might influence participants' ability to detect differences between real and virtual rotations. Thus, future work should explore the effects of spatialized sound during scenarios involving a richer soundscape (e.g., additional sound sources) as well as scenarios where audition might play a more central role for spatial cognition (e.g., dimply lit or foggy environments).

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