Acoustical Manipulation for Redirected Walking

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ABSTRACT

Redirected Walking (RDW) manipulates a scene that is displayed to VR users so that they unknowingly compensate for scene motion and can thus explore a large virtual world on a limited space. So far, mostly visual manipulation techniques have been studied.

This paper shows that users can also be manipulated by means of acoustical signals. In an experiment with a dynamically moving audio source we see deviations of up to 30% from a 20 m long straight-line walk for male participants and of up to 25% for females. Static audio has about two thirds of this impact.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Auditory feedback*; User studies; • **Computing methodologies** → *Perception*;

KEYWORDS

Virtual Reality, Virtual Locomotion, Redirected Walking, Spatial Audio, Motion Perception.

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1 INTRODUCTION

Redirected Walking (RDW) exploits tolerances in the human visual perception to expand the virtual space in a limited physical space. The main idea is to manipulate the displayed VR scene so that users compensate for scene motion without noticing it. RDW works because humans primarily rely on vestibular, visual and auditory cues for balance and orientation. The effect of visual cues has been studied [Nilsson et al. 2016; Serafin et al. 2013; Souman et al. 2009]. Without any absolute visual reference humans unconsciously redirect their straight-line walk and end up in a circle (turn scaling from +49% to -20% and distance scaling from +26% to -14% [Meyer et al. 2016; Steinicke et al. 2010]). Visual RDW (vRDW) affects estimations of spatial locations of objects stronger than acoustical RDW (aRDW). Users walk either towards [Meyer et al. 2016; Nogalski and Fohl 2016, 2017; Serafin et al. 2013] or around [Nilsson et al. 2016] a physical audio source. However, it is unclear how these results extend to tracking areas above $4 \times 4\ m$ without the users noticing the manipulations.

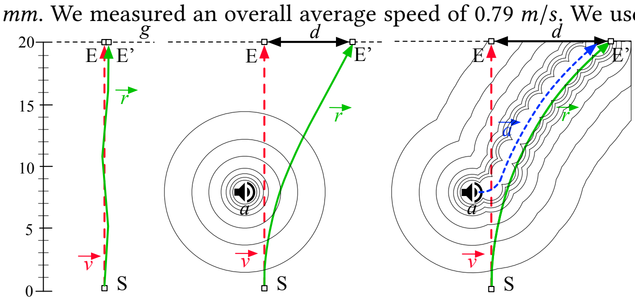
This paper presents an experimental study on the effects of audio signals on VR users. We show that acoustical manipulation can also extend the virtual environment (VE) and extend the possibilities of RDW. Earlier works do not apply for large scale multi-user VR applications as there is no sound source per user. Instead of applying visual effects to force users to walk curvatures we also let them walk naturally in VR and observe the effect of spatial audio on their locomotion. We then deduce a curvature gain that is reproducible, applicable and does not harm immersion.

Section 2 introduces the experimental setup, Section 3 discusses the results, and Section 4 concludes.

2 EXPERIMENTAL SETUP

In the VE of our experiment the participants only see a small red dot in the middle of their VR display. Similar to a cross-hair, it tells them in which direction they should walk for 20 m straight ahead, from the starting point S, along $\vec{v}$, to the end point E in Fig. 1(a-c). The virtual floor is plain and has a uniform texture. There are stable external lights and acoustical conditions. This reduces the visual effects to a minimum so that users cannot orientate themselves visually, except for the red dot that stays in the middle even if their real trajectory $\vec{r}$ deviates from $\vec{v}$. The dot turns with the yaw-body-axis so that the users do not notice their turns. The red dot does not change, regardless of the proximity to E.

For the study we have ten participants (5 ♀ and 5 ♂, average age 26 years [16 - 48]; average height 1.74 m [1.49 m –1.81 m]; nobody handicapped or disabled). None of the test subjects is aware of our research goal. Each of the participants walks from S to E three times at a normal speed. To exactly record $\vec{r}$ we use a Nikon iGPS laser-based positioning system with a precision in the range of mm. We measured an overall average speed of 0.79 m/s. We use



(a) No audio. (b) Static audio. (c) Dynamic audio.

Figure 1: Three scenarios to gauge the effect of an audio cue. Virtual walking path $\vec{v}$ (20 m from S to E), real walking path $\vec{r}$ terminating in E', and deviation d. Not to scale.

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Table 1: Deviations in *m*.

	No audio		Static audio		Dynamic audio	
♀	avg.	0.55 (2.8%)	avg.	3.38 (16.9%)	avg.	5.02 (25.1%)
	min.	0.01	min.	3.16	min.	4.64
	max.	0.88	max.	3.54	max.	5.32
♂	avg.	0.74 (3.7%)	avg.	3.92 (19.6%)	avg.	6.00 (30.0%)
	min.	0.30	min.	3.87	min.	5.52
	max.	0.95	max.	3.93	max.	6.96

Sennheiser HD 598 headphones and render binaural audio using the spatial audio framework *CINEMA on the GO*.

In the first walk there is **no audio**, see Fig. 1(a). The participant gets accustomed to the VE. We use the recorded $\vec{r}$ as a user-specific baseline to normalize the trajectories of the next two walks.

The setup for the next two walks is shown in parts (b) and (c) of Fig. 1. In both scenarios there is an audio source that is already emitting sound before a participant starts walking. The participant cannot hear the sound before entering the 8 *m* radius around it. The loudness increases linearly with the proximity of the participant to the virtual audio source. The virtual speaker is at position a that is 8 *m* into the walk and 1 *m* to the left of the straight line from S to E. We play a loud and disturbing construction noise through the headphones (preliminary study: all users perceive 65 *dB* in just 1 *m* distance to be disturbing) that does not otherwise distract the users as they recognize such sounds from real life. Since this constant sound does not appear suddenly but gradually grows louder, the users are not surprised. There is no evasive movement in the recorded trajectories, i.e., users perceive our VE to be natural.

In the second walk (**static audio**, Fig. 1(b)), the virtual source of the sound statically stays where it is, i.e., the participants leave the dying sound behind them once they pass a.

In the third walk (**dynamic audio**, Fig 1(c)), initially a is located at the same spot. But the moment a participant is 8 *m* into the walk, i.e., on the same level as a, the virtual speaker smoothly approaches the walking participant from the left until the distance is 1 *m*. From there onwards the virtual source of the sound follows the participant with a constant distance of 1 *m*, see $\vec{a}$, so that the sound stays loud for the remainder of the walk.

To gauge whether an audio cue can have an effect on the participants, we measure the distance d between E and E'. Both points are located on the (conceptual) dashed horizontal line g that is not visible in the VR scene. If E and E' differ, then acoustical influence does redirect the participants' real movements $\vec{r}$, especially as we subtract any baseline effects.

3 RESULTS

Table 1 shows the deviations d. With **no audio** there is almost no deviation, neither for male nor for female participants. The users feel comfortable as the red dot helps them to walk straight.

For the two scenarios with an audio signal we normalize the measured deviations by subtracting the user-specific baseline deviations from them. This differentiation enables to precisely determine the deviation for each user based on her/his baseline walk. As expected, all users confirmed that they hear the audio on their left ear and dislike the construction noise.

With **static audio** the male participants redirect their movements by at least 3.87 *m* (up to 3.93 *m*, avg. 3.92 *m*) whereas the females deviate by at most 3.54 *m* (avg. 3.38 *m*).

The redirection caused by the **dynamic audio** is about 50% stronger than the deviation caused by the static audio. Dynamic audio causes the male subjects to redirect their movements up to 6.96 *m* with an average of 6.00 *m*. The effect of the dynamic audio on the females is far less pronounced. They deviate at most 5.32 *m* (avg. 5.02 *m*). Our findings are in line with previous studies that state that men respond stronger to such manipulations than women.

Dynamic audio can thus manipulate the average heading orientation by 14° to 22°. This is about 50% of what visual RDW manipulations achieve in the related work [Meyer et al. 2016; Nilsson et al. 2016; Serafin et al. 2013]. We estimate that with just acoustical redirection we can turn a user's straight-line walk into a circle with a radius of 29 *m* (at least 42 *m*). This corresponds to a curvature gain of 0.035 (at least 0.045). Visual redirection alone achieves a radius of 22 *m* [Steinicke et al. 2010].

In preliminary experiments with other subjects we also found that the acoustical manipulation is less effective if the virtual audio source is more than 1 *m* away from the subject. This is also supported by the results in Table 1 since the dynamic audio source seems to keep pushing while users continue to walk. While Fig. 1 is not to scale, the slope of $\vec{r}$ summarizes what we see in the measurements: $\vec{r}$ turns back into a straight line when participants get away from the static virtual speaker, see Fig.1(b). In Fig.1(c) the trajectory $\vec{r}$ gets more and more curved because of the trailing $\vec{a}$.

4 CONCLUSION

Humans on straight-line walks redirect their movement away from loud audio sources. A dynamic audio source can manipulate males to change their walking direction by up to 30% (6.96 *m* deviation in a 20 *m* walk) and females by up to 25%. Static audio has about two thirds of this impact. Previous related work on RDW solely uses visual effects to manipulate VR users. Our findings on acoustical manipulations suggest that adding them to the visual manipulations may lead to an even more effective RDW.

Future work will cover the 3D combination of aRDW and vRDW. We will also work on the impact of different types of sound samples, rolloff factors, and sound intensities. We use this method to avoid user collisions with virtual objects (e.g. walls).

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REFERENCES

F. Meyer, M. Nogalski, and W. Fohl. 2016. Detection thresholds in audio-visual redirected walking. *Proc. Sound and Music Comp. Conf. (SMC)* 16, 1 (2016), 17–27.

N. C. Nilsson, E. Suma, R. Nordahl, M. Bolas, and S. Serafin. 2016. Estimation of detection thresholds for audiovisual rotation gains. In *Proc. Virtual Reality Conf.* IEEE, Hamburg, Germany, 241–242.

M. Nogalski and W. Fohl. 2016. Acoustic redirected walking with auditory cues by means of wave field synthesis. In *Proc. Virtual Reality Conf.* IEEE, Hamburg, Germany, 245–246.

M. Nogalski and W. Fohl. 2017. Curvature gains in redirected walking: A closer look. In *Proc. Virtual Reality Conf.* IEEE, Hamburg, Germany, 267–268.

S. Serafin, N. C. Nilsson, E. Sikstrom, A. De Goetzen, and R. Nordahl. 2013. Estimation of detection thresholds for acoustic based redirected walking techniques. In *Proc. Virtual Reality Conf.* IEEE, Orlando, Florida, 161–162.

J. Souman, I. Frissen, M. Sreenivasa, and M. Ernst. 2009. Walking straight into circles. *Current Biology* 19, 18 (2009), 1538–1542.

F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe. 2010. Estimation of detection thresholds for redirected walking techniques. *IEEE Trans. Visualization and Computer Graphics* 16, 1 (2010), 17–27.