Estimation of individual redirected walking thresholds using standard perception tests

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Abstract

Redirected walking (RDW) allows users to interact with a Virtual Environment (VE) much larger than the real space. However, there is a limit to how much a user can be redirected such that immersion in the VE is still preserved. While much effort has been spent on identifying this limit, so-called redirected walking thresholds, these thresholds are more a general guideline than being personalized for each user. Since individuals' differences in perception play an important role in users's experience in a redirected VE, there is potential to optimize the thresholds using these differences.

In this paper, we propose an investigation on the relationship between redirected walking thresholds (RDTs) and perception traits such as visual dependency, susceptibility to visual-vestibular conflicts, and sensitivity to internal body changes, which can be measured in postural sway, rod-and-frame, vection and interoception tests. Consequentially, we will investigate the potential of using these tests as tools for the estimation of personalized RDTs.

Keywords: redirected walking, threshold, postural sway, rod-and-frame, vection, interoception.

Concepts: •**Human-centered computing** → *Virtual reality;* •**Applied computing** → *Psychology;*

1 Introduction

One of the most immersive ways of interaction with a VE is being able to physically walk in it [Usoh et al. 1999]. However, the challenge in real walking arises when the VE is larger than the physical space. [Razzaque et al. 2001] were the first to define RDW techniques as one method to overcome this challenge. RDW techniques work based on the fact that when dealing with conflicting visual, vestibular and proprioceptive cues, humans tend to trust their visual cues, and therefore their perception can be "manipulated" through the Head Mounted Display (HMD). Using RDW techniques, the one-to-one mapping between the real world and the virtual world can be scaled by 3 types of gain: translational, rotational and curvature gain. However, there is a limit to these gains, identified first by [Razzaque 2005] using one-up/one-down staircase method for its time efficiency. [Steinicke et al. 2008] later identified these gains using the constant stimulus method. [Bruder et al. 2012] performed a similar set of experiments and found that while rotational and translational gain thresholds approximate the results from [Steinicke et al. 2008], there is difference in the curvature gain threshold, and discussed that it could be due to a different VR setup or subject groups. The difference in thresholds obtained in these tests raises the question: What are the factors that influence a person's RDTs? Two fundamental types of factors are proposed: intrinsic and extrinsic. Intrinsic factors are factors specific to a person's perception such as visual dependence, how sensitive they are to visual-vestibular conflict or internal body changes, etc. Extrinsic factors include walking velocity [Neth et al. 2012], environment setup, cognitive load, etc. In the scope of this paper, we focus mainly on the intrinsic factors: visual dependence, susceptibility to visual-vestibular conflict and interoception.

Visual dependence is a measure of how much a person depends on visual information during sensory integration. Here, we are particularly interested in how much weighting subjects give to visual cues as compared to vestibular and proprioceptive cues when performing actions critical to the walking process such as estimating their spatial orientation or maintaining their balance. A high visual weighting could imply higher RDTs since the user could be more susceptible to visual "manipulation". The so-called rod and frame test by [Witkin and Asch 1948] is one of the established tests measuring the dominance of visual over gravitational vestibular cues. In the test, a rod in the middle of a tilted square frame is presented, and the subjects are asked to rotate the rod until they think it is vertical. People are normally influenced by the visual sensation of the tilted frame, and thus deviating from the true vertical. Another visual dependence test is Romberg's test [Romberg 1853], involving the three sensory modalities: visual, proprioceptive and vestibular. For the test, subjects' deviations of the center of pressure (COP) while standing are measured with eyes open and eye closed and the ratio between these are computed. This ratio signifies how much the user relies on visual information for maintaining postural balance. Therefore, we hypothesize that a high Romberg ratio could correlate to higher RDTs.

When there is conflict between visual and other sensory cues, an illusion of self-motion could occur, which is called vection. Traditionally, a vection test is performed in an optokinetic drum where a subject sits statically in the middle of a rotating drum with regularly illuminated stripes. Once the subject feels self-motion, the time will be recorded as on-set vection. Since a similar type of sensory conflict (visual-vestibular-proprioceptive) happens in RDW, we hypothesize that a measure of vection - **susceptibility to visual-vestibular conflict** - could correlate positively with RDTs.

Interoception refers to a person's sensitivity to internal body changes. Interoception tests are normally cardiac-based procedures: in the commonly used heartbeat detection task, subjects are asked to identify whether a series of sounds is in sync or not with their current heartbeats. Interoception was suggested by [Faivre et al. 2015] to have mutual influences on vision, and we hypothesize that the more aware a person is of his/her interoceptive cues, the less he/she relies on visual cues in case of conflict, and therefore will have lower RDTs. Despite the wide use of these aforementioned tests of perception traits in clinical and neurological research, to our knowledge, none has been used in the context of RDW.

2 Experimental Setup

2.1 Perception trait tests

For the **rod and frame test**, subjects wear an Oculus DK2 and are shown a series of 20 rod and frame settings (10 for each rotating direction [Takasaki et al. 2012]). The rod is drawn as a circle dot-

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ted line to prevent jaggedness due to limited HMD resolution. The subjects are asked to rotate the rod using a joystick until they think it is vertical. The errors from the true vertical are recorded and the mean of absolute errors will be the test score. In the **Romberg's test** we use a Nintendo Wii balance board, which was proved to be sufficient and comparable to lab grade devices [Clark et al. 2010]. The subjects stand on the board first with eyes open and fixated on a target in the room for 2 minutes, and then eyes closed for 2 minutes. The deviation of the COP is recorded for both cases, and the Romberg's quotient is computed as a test score. For the **vection test**, a virtual optokinetic drum is built and shown to subjects wearing Oculus DK2. At the onset of vection, the subjects press a button on the joystick, and rate the vection strength on a 0-100 scale. The onset time is recorded as test score. For the **interoception test**, the subjects sit still on a chair, electrodes attached, with hands faced up and put on the legs to prevent accidentally feeling their heartbeats. 40 series [Kleckner et al. 2015] of 10 beeping tones, triggered by the subjects's heartbeats, are then played to the subjects. The synchronous signal is played with a delay of 200ms (perceived as coincident with the heartbeats), and the asynchronous signal 500ms [Wiens and Palmer 2001]. After each trial, the subjects answer verbally whether the sound was in or out of sync with their heartbeats. The number of correct answers is the test score.

2.2 Threshold identification test

The VR system used for threshold identification consists of an Oculus DK2 with embedded SMI eyetracker, an Intersense IS-1200 tracking system, and a backpack with a notebook to render the scene. In order to remove the possible effects of extrinsic factors such as distractions from the environment, the scene is designed with plain background and floor, and one single target (Figure 1). The experiments are carried out in a tracking room of 6.6m x 13m. The RDTs are identified using two interleaved 2-Alternative-

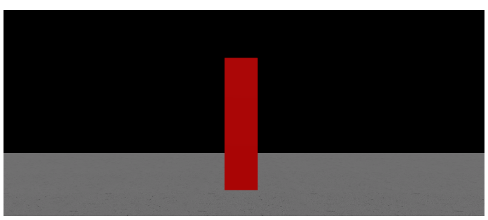

Figure 1: *Scene built for the identification of RDT*

Forced-Choice three-down/one-up staircases with fixed step size for left and right directions (in the case of curvature and rotational gain to account for left-right asymmetry). The settings of the staircases such as ratio between step up and down, stopping condition, number of reversal points used for calculating the threshold follow recommendations from [Garcıa-Pérez 1998]. For curvature gain identification, after walking 7.5m towards the target, the subjects answer a question: "Were you going LEFT or RIGHT?" using the embedded eye tracker. Depending on the correctness of the answer, the staircases are updated automatically and the subjects move on to the next target. The experiment finishes when the number of reversal points has been reached.

3 Conclusion and future work

The investigation on how perception traits influence RDW not only offers a tool for estimating personalized RDTs, consequently optimizing experience in a VE, but also could provide valuable insights to the multi-sensory integration model. The thresholds obtained, however, are the most conservative values since all distractions from the environment are excluded, and there is no extra cognitive load required for the task. Therefore, the VR experience could be further improved by research on how extrinsic factors play a role in RDW. One of the most interesting questions would be how to design an environment such that RDTs are maximized.

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