Visual Capture of Gait in Redirected Walking

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Introduction

Virtual reality (VR) applications using head mounted displays (HMDs) allow users to deeply immerse in a virtual world. There is, however, one obstacle to a full-blown immersion, dubbed the "locomotion problem". It concerns the user's navigation through large virtual environments. While virtual worlds can easily be expanded infinitely, physical locomotion remains constrained by the size of the available room. Redirected walking is a technique that allows users of virtual reality applications to explore virtual environments larger than the available physical space [1]. This is made possible by manipulating the walking trajectory of users through visual rotation of the virtual surroundings, without the user noticing the interference. This causes the user to correct for the rotation by walking on a curved pathway (see Figure 1). At the extreme, a user could proceed infinitely far straight forward in the virtual environment while walking in full circle in reality. Apart from its value for designing VR-applications, the issue of redirection is of considerable interest for behavioral and psychological research. During walking, redirection causes a mismatch between visual and bodily feedback, the latter comprising vestibular, proprioceptive and somatosensory cues. Experimentally induced sensory mismatch situations have long been used in psychology to study various processes such as action monitoring [2] or feeling of agency [3]. In this study we focused on the important, yet unsolved question of how individual differences influence detection thresholds of redirected walking. Knowledge of these differences will not only help improve virtual reality applications, but also deepen our understanding of how humans process multisensory conflicts during locomotion.

Methods

In an explorative study with 60 healthy participants (age 18-35) we determined individual redirected walking detection thresholds ("redirection thresholds"), using a Bayesian adaptive method for threshold estimation. Participants also underwent comprehensive cognitive testing and an assessment of psycho-physical traits. Tests included visual-dependence measurements in various contexts (rod-and-frame task, assessment of the Romberg quotient, measurement of vection susceptibility), but also addressed non-visual body perception and control (blind veering, balance stability, interoception, somatosensory amplification). We used a linear mixed model procedure, accounting for participants as a random factor, to analyze the relation of test performances with individual redirection thresholds.

Results

When testing the assessed test performances univariately, a positive relation of individual redirection thresholds with the performance in the rod-and-frame test and with vection onset-time emerged. A negative relation with redirection thresholds was found for the Romberg quotient and blind sway. When combining the tested variables together in one model, only the effect of the rod-and-frame test performance remained significant.

Discussion

Our results allow to pinpoint the neuropsychological factors associated with an individual's sensitivity to detect manipulations of gait while walking in a virtual reality environment. Of all tested variables, performance in the rod-and-frame test showed the most prominent association to redirection thresholds. Specifically, the more visual dependent a participant was in the rod-and-frame task, the worse he/she performed at detecting redirected walking manipulations. This result supports the view that visual dominance over body-related signals constitutes a "visual capture of gait", which hampers the detection of any locomotor perturbation. The paradigm of redirected walking may be used for various further research questions regarding the processing of multisensory signals during active

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walking. Such research-based implementations of redirected walking could also be applied to specific clinical populations suffering from impairments of action monitoring or sensory integration during locomotion (see [4]).

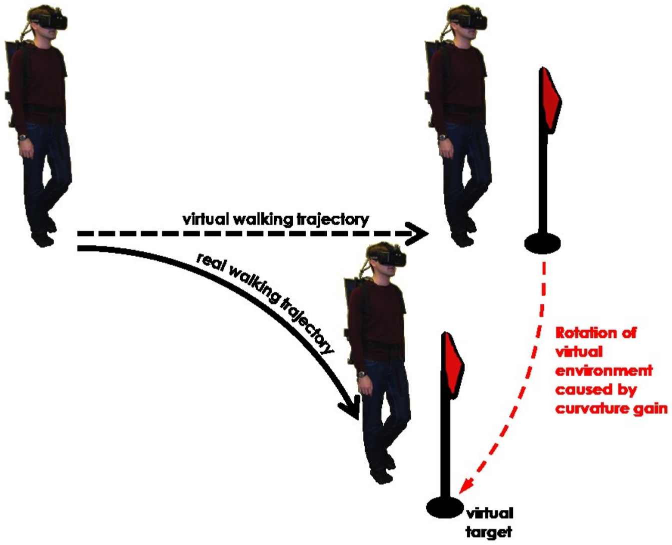

Figure 1. Illustration of a walking trajectory manipulation through redirected walking (note: the unit of curvature gain corresponds to 1/radius of trajectory curvature).

Ethical Statement

All experimental procedures were approved by the "Kantonale Ethikkomission Zurich" (BASEC Nr. 2016-01153).

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