Immersive Robot-Assisted Virtual Reality Therapy for Neurologically-Caused Gait Impairments

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Figure 1: Illustration of two scenes in the virtual environment that was presented during the walking exercise.

Abstract

This paper presents an immersive Virtual Reality (VR) therapy system for gait rehabilitation after neurological impairments, e.g., caused by accidents or strokes: The system targets increase of patients' motivation to perform the repeated exercise by providing stimulating virtual exercise environments with the final goal to increase therapy efficiency and effectiveness. Instead of simply working out on immobile stationary devices, the system allows them to walk through and explore a stimulating virtual world. Patients are immersed in the virtual environments using a Head-Mounted Display (HMD). Walking patterns are captured by motion sensors attached to the patients' feet to synchronize locomotion speed between the real and the virtual world. A user-centered design process evaluated usability, user experience, and feasibility to confirm the overall goals of the system before any sensitive clinical trials with impaired patients can start. Overall, the results demonstrated an encouraging user experience and acceptance while it did not induce any unwanted side-effects, e.g., nausea or cyber-sickness.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

1 Introduction

Patients with neurologically-caused gait impairments improve their functional walking ability by repeated physical walking exercises. Such exercises require therapy equipment which is capable of guiding, stabilizing, and securing patients during work out. The damages might be severe, and the abilities for holding the balance or walking upright might first have to be recovered. This requires heavy-duty therapy equipment, e.g., walking robots with exoskeletal features capable of supporting and securing all potential patients while guiding them through the exercises. Although robot-assisted gait training outcome measures are promising, therapy progress is often restricted by boredom, fatigue, lack of motivation during exercises and lack of cooperation in attending therapy [7]. The high degree of sensorimotor contingencies realized by state-of-the-art HMD-based VR-systems provides the ability to immerse patients in a motivating interaction context during gait training. In this paper, we present (1) a VR application that aims to increase motivation during robot-assisted gait rehabilitation and (2) the results of a preliminary feasibility study with healthy participants.

2 Related Work

Augmenting traditional robot-assisted gait training with interactive media devices has been suggested to increase therapy effectiveness: for instance, Mirelman et al. [6] found an increase of velocity and distance walked when patients interacted with an interactive desktop application during robot-assisted training. The effects were maintained at three months follow-up. A review of interventions that include interactive systems in gait rehabilitation shows a promising trend that VR augmented training improves treatment outcomes [1]. Previous work mostly uses semi-immersive display technology, like desktop screens, for stimulus presentation. To the best of our knowledge, the proposed application is the first project to include a HMD based VR interaction scenario in robot-assisted gait rehabilitation, allowing for a high degree of sensorimotor contingency, consistently aligning VR stimuli to head and body movements.

3 Experimental Design

The application aims to increase motivation and self-efficacy during robot-assisted gait training. Walking movements of lower limbs are translated into a forward shift within a diversified virtual environment. The translation follows a natural movement pattern analog to the head movement performed during walking. Forward translation is scaled to increase the salience of movements. The current virtual environment consists of different natural scenes, illustrated exemplarily in Figure 1. For preliminary assessment, we assumed VR augmentation increases the motivation to engage in walking exercises compared to walking alone. The study followed a single-blind, randomized repeated measures design with the single factor

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VR augmentation or no VR augmentation during a walking exercise on a cross-trainer. The healthy participants completed each condition once in randomized order. In each condition, participants were instructed to walk on the cross-trainer for two minutes in normal walking pace and to complete questionnaires subsequently. In the VR augmentation condition participants wore a HMD and were exposed to the virtual environment.

Figure 2: A participant walking on the cross-trainer in the VR augmentation condition (left) and the non-augmentation condition (center). Robotic-assisted gait device that will be used for the clinical trial (right).

4 Methods

4.1 Participants

In this study 21 (11 female) healthy undergraduate students volunteered to participate in exchange for course credit. The age of the participants ranged from 19 to 35 ($M = 24.19$, $SD = 4.38$). All reported normal or corrected-to-normal vision and the absence of motor impairments.

4.2 Apparatus

For the experiment, a traditional cross-trainer was augmented with a VR-system. VR Stimuli were presented in an HTC Vive head-mounted-display (HMD). During the experiment participants were positioned on a stationary cross-trainer, placing their hands on the handles and feet on the pedals, as illustrated in Figure 2. Vive sensors were attached to the cross-trainer to track the movement of the feet.

4.3 Stimuli

The virtual environment consisted of natural landscapes. Walking movements were mapped to transitions in the virtual environment that simulate walking. Figure 1 illustrates the presented environment. Additionally, natural sound elements were presented which matched the context of the visual stimuli.

4.4 Measures and Analysis

As a primary outcome measure, the Intrinsic Motivation Inventory (IMI) [5] was used to assess intrinsic motivation for the walking exercise. As secondary outcome measures, first, the NASA Task Load Index (NASA-TLX) [2] was conducted to assess the perceived workload of using the cross-trainer, using a seven-point Likert scale from 1 (*low*) to 7 (*high*). Second, state affect during the exercise was assessed with the International Positive and Negative Affect Schedule (PANAS) Short Form (I-PANAS-SF) [8], using a five-point Likert scale from 1 (*low*) to 5 (*high*). Third, the User Experience Questionnaire (UEQ) [4] was conducted for a baseline assessment of the user experience in the VR augmentation condition only, using a seven-point Likert scale from -3 (*low*) to 3 (*high*). The Simulator Sickness Questionnaire [3] was conducted before and after VR exposure to control for unwanted side-effects. Two-tailed paired t-tests were calculated to compare within-group differences. A priori significance level was set at $p < .05$ for all tests.

5 Results

There were no significant differences in the IMI subscales. The NASA-TLX subscale Mental Demand revealed significantly higher score ($t(20) = 3.07$, $p = .006$) for the VR augmentation condition ($M = 2.23$, $SD = 1.14$) compared to the non-augmentation condition ($M = 1.42$, $SD = 0.93$). The other NASA-TLX subscales showed no significant differences. The I-PANAS-SF positive affect subscale showed a significant higher score ($t(20) = 4.30$, $p < .001$) for the VR augmentation ($M = 3.81$, $SD = 0.66$) compared to the non-augmentation condition ($M = 3.37$, $SD = 0.75$), whereas the negative affect subscale showed no significant difference. The UEQ subscales in general revealed high user experience scores for the application: Attractiveness ($M = 1.79$, $SD = 1.02$), Perspicuity ($M = 1.75$, $SD = 0.93$), Efficiency ($M = 0.94$, $SD = 0.81$), Dependability ($M = 0.77$, $SD = 0.90$), Stimulation ($M = 1.89$, $SD = 1.00$), and Novelty ($M = 1.92$, $SD = 0.89$). The total SSQ score (ranging from 0 (*low*) to 48 (*high*)) did not significantly increase between pre ($M = 23.69$, $SD = 29.76$) and post ($M = 33.30$, $SD = 36.54$) assessment ($t(20) = 1.36$, $p < .19$).

6 Conclusion

In this work, we proposed a new approach for increasing the motivation of robot-assisted gait rehabilitation procedures by augmenting traditional settings with a VR system. The user-centered design process included a first preliminary study with healthy participants. It showed encouraging results concerning the user experience and acceptance, furthermore, no unwanted side effects occurred. One important part of our future work is to evaluate the application with stroke patients at different stages of motor deficits with a robotic-assisted gait device as displayed in Figure 2. Furthermore, we will include game mechanics to foster longterm intrinsic motivation.

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