Immersive Virtual Reality for the Assessment and Training of Spatial Memory: Feasibility in Neurological Patients

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***Abstract*— Immersive Virtual Reality (VR) shows promise for cognitive diagnostics and rehabilitation as it can present patients with realistic, life-like environments, and allows to precisely record behavioral performance to infer indicators of cognitive processes. The aim of our study was (1) to test feasibility of immersive VR in neurological patients with acquired brain injury, and detect limits in its applicability, and (2) investigate the effects of immersion and presence, usability and general motivational aspects as well as symptoms of cybersickness on the user experience. For this purpose, a novel VR task, the immersive Virtual Memory Task (imVMT), was developed and tested to measure spatial memory in neurological patients. Preliminary data will be discussed with a focus on feasibility.**

Keywords— virtual reality, neuropsychological diagnostic, spatial memory, feasibility

I. Introduction

Neuropsychological assessment aims to measure specified cognitive functions while, ideally, being ecologically valid and predictive of a patient's performance in everyday life. To achieve this aim, Virtual Reality (VR) – and particularly immersive VR – holds a high potential to achieve this aim as virtual environments (VE) can present an everyday-like world and realistic objects to a user, while task difficulty can be parametrically increased, and behavior can be precisely measured. Therefore, VR may be a suitable tool to measure cognitive function in (e.g., neurological) patients [1, 2].

With rapid technological advancements and increasing availability of VR systems, clinical VR applications are increasingly being used as diagnostic as well as rehabilitation tools to detect and train cognitive, psychological, and motor impairments [3, 4]. Preliminary work in this field provides support that VR interventions high in ecological validity lead to behavioral changes in daily life, confirming the transfer from the virtual to the real world [5].

Individuals immersed in VEs can interact with virtual objects in real-time through multiple sensory modalities [6]. Therefore, virtual worlds combine experimental control with the potential to enhance the real-life transfer by providing interactive and realistic stimuli [7]. Nevertheless, with respect to the applicability in a clinical population, there are several open questions: To what extent are patients with motor, perceptual, or cognitive deficits able to adjust to the interaction with the VE and do they tolerate head-mounted displays (HMD), which are necessary to present immersive scenes?

II. Aims and Perspectives

The VReha project "Virtual Worlds for Digital Diagnostics and Cognitive Rehabilitation" (www.vreha-project.com) examines the applicability of immersive VR scenarios in patients with different neurological impairments. In the consortium, clinicians, psychologists, and software engineers jointly develop and evaluate ecologically relevant diagnostic and therapeutic VR scenarios. Realistic VEs – resembling patients' everyday lives – are used to assess cognitive functions and apply individually tailored immersive training programs. With visual input delivered through a HMD and controller-free interaction in the VE, the project investigates (and aims to maximize) the feasibility of immersive VR in neurological patients.

One branch of the VReha project focuses on the cognitive component of spatial memory. Since the natural space is 3D, spatial memory is hard to examine with traditional 2D paper-and-pencil or computerized tasks. We therefore developed a novel VR task, the immersive Virtual Memory Task (imVMT), to assess (visuo)spatial memory in a both sensitive and ecologically valid manner. Spatial memory deficits occur early in Alzheimer's and in a number of other neurological diseases [8]. Therefore, measures to sensitively detect deficits in spatial memory are of high clinical relevance.

We will present evaluation results of the imVMT with neurological patients with respect to the following goals: (1) test the feasibility of immersive VR in neurological patients

with acquired brain injury, and detect limits in its applicability (e.g., due to motor or other functional impairments) and (2) use specifically designed questionnaires aiming to investigate the effects of immersion and presence, usability and general motivational aspects as well as symptoms of cybersickness on the user experience.

III. Methods

A. Task and experimental procedure

The imVMT is based on the non-immersive virtual memory task (VMT) [9] - a spatial memory task, in which patients are asked to recall the location of everyday-life items on a table. Participants complete the task on a desktop computer and receive visual feedback of the objects' correct positions and deviations. Correlations between performances in established tests of visual short-term memory, like the Rey-Osterrieth Complex Figure Test, and the VMT were found.

Similarly, in the imVMT, the task is to memorize the location of up to seven everyday-life objects on a virtual table. In contrast to the VMT, the VE in the imVMT is immersive through usage of a HMD (Oculus Rift) and natural (i.e., controller-free) hand interaction (with a Leap Motion). After memorization, patients are asked to reconstruct the original spatial arrangement of the objects on the table. The use of VR allows a detailed record of performance in time and space, and to define precise outcome measures, e.g. completion time, placement errors, and trajectories. These can be used to infer underlying cognitive processes of spatial memory. For a systematic evaluation of the imVMT, we compiled and developed questionnaires that assess (1) immersion and presence, (2) usability and general motivational aspects as well as (3) symptoms of cybersickness.

B. Study sample

The study sample consisted of patients of the Clinic for Cognitive Neurology at the University of Leipzig, Germany. Patients with acquired brain injury of different etiologies (e.g., TBI, stroke, encephalitis, Alzheimer's disease), diverse levels of cognitive functioning, and a broad range of neurological symptoms (e.g., hemiparesis, hemianopia) took part.

IV. Preliminary results

The preliminary results from the Simulator Sickness Questionnaire (SSQ) [10] showed that patients, who completed the imVMT, had low SSQ values, which indicates that no symptoms of cybersickness, such as headache, eyestrain, or nausea, were induced by the VR setup and task. Moreover, none of the patients terminated the imVMT due to discomfort or dizziness. With respect to the level of immersion and presence, the majority of patients reported that the virtual objects looked real to them, they perceived the interaction as natural, and they felt immersed in the VE. However, the hand interaction was only partly perceived as natural, because delays in motion control impeded an intuitive usage of the system. Moreover, patients felt moderately present while performing the virtual task and enjoyed using both the VR system and the imVMT. Most of the patients could consider a regular use of the imVMT and, thus, there was high usability and overall satisfaction with the task.

V. Discussion and challenges for the future

In this project, we investigate with a novel immersive VR task whether the clinical use of immersive VR is generally feasible in neurological patients and, particularly, how the impact of immersion and presence, usability and general motivational aspects as well as symptoms of cybersickness affect patients' experience in the VE. Overall, patients felt immersed and present in the VE, had an open attitude towards the VR system and no indications for cybersickness were found. So far, only patients with mild impairments were included. These results encourage application in more severely impaired patients. The imVMT is easy to handle and the level of difficulty can be adapted for the patients' individual needs. In this VR setup and task, neurological patients with a variety of motor, perceptual, and cognitive deficits intuitively interacted with the VR system, tolerated the HMD, and showed no side effects (e.g., cybersickness). Therefore, VR in general and the imVMT in particular promises to allow the assessment of cognitive functioning in an experimentally controlled and ecologically valid manner.

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