Harnessing the experience of presence for virtual motor rehabilitation: towards a guideline for the development of virtual reality environments

T Schüler[1], L Ferreira dos Santos[2], S Hoermann[3]

[1]Institute of Computer Science, University of Osnabrück,
Albrechtstraße 28, Osnabrück, GERMANY

[2]Rehabilitation Robotics Group (Fraunhofer IPK/ TU Berlin) &
DFG Research Training Group prometei, Technische Universität Berlin,
Marchstraße 21, Berlin, GERMANY

[3]Department of Medicine (DSM) & Department of Information Science, University of Otago,
60 Clyde Street, Dunedin, NEW ZEALAND

thschuel@uos.de, *lsantos@zmms.tu-berlin.de*, *simon.hoermann@otago.ac.nz*

[1]*www.inf.uos.de,* [2]*www.prometei.de,* [3]*www.otago.ac.nz*

ABSTRACT

The experience of presence has been shown to be important for virtual motor rehabilitation. Despite its importance, current research and therapy systems often make only limited use of it. This article introduces a conceptualization of presence that provides a guideline for the implementation of virtual rehabilitation environments. Three types of visual feedback in virtual rehabilitation systems are linked to three dimensions of presence. In particular it is shown how movement visualization, performance feedback and context information correspond to the presence dimensions: spatial presence, involvement and realness. In addition, practical implications are discussed to support the development of future virtual rehabilitation systems and to allow better use of the experience of presence for virtual motor rehabilitation after stroke.

1. INTRODUCTION

Virtual reality (VR) systems have been shown to be effective for the treatment of patients with motor impairments; however, the exact characteristics that lead to improvements are not well understood and more research is still needed to optimize therapeutic outcomes and VR systems (Laver et al, 2011). In VR systems patients interact with virtual environments: their movement is tracked with specific devices and is often visualized as movements of a virtual avatar. Today it is not known exactly how features of a virtual environment impact upon treatment outcomes. However, a key role for motivation and general effectiveness has been assigned to the experience of presence. Presence is defined as the illusion of nonmediation and the feeling of “being there” in the virtual environment (Lombard & Ditton, 1997). Consequently patients who experience presence during VR-based treatment focus on the game world that demands active participation. Therefore effective training may be supported through presence, yet few studies have examined this in therapeutic VR application.

With this article we attempt to clarify the importance of presence for VR-based treatment of motor disabilities after stroke. We identify three distinct feedback types that are provided by virtual rehabilitation systems. These types match well with the three dimensional model of the presence experience proposed by Schubert et al. (2001). We discuss how the feedback types and presence dimensions may foster recovery of motor function and suggest practical implications that guide future development of virtual rehabilitation systems.

1.1 Dimensions of presence

Schubert et al. (2001) proposed a three dimensional model of the presence experience. They identified three distinct factors contributing to an overall experience of presence. These factors were spatial presence (construction of a spatial mental model of the VR), involvement (attention allocation and concentration on the VR) and realness (comparison of the VR experience against one in a physical world).

Spatial presence has been linked with embodied theories of cognition (Riva et al, 2010). Specifically the ability of a subject to act within a virtual environment (agency) is thought to determine a coherent spatial mental model of that environment. Importantly it is the subject's individual perception of action potentials rather than an objective availability per se that constitutes spatial presence. Factors that contribute to involvement include technical and human conditions (Schubert et al, 2001) as well as the attention towards a virtual environment. It can be influenced through the choice of hardware components, but it is also dependent on the subjects' motivation and interest. The realness dimension represents a comparison of the experience made in the virtual environment with a similar one in the real world (Schubert et al, 2001). The realness judgment is influenced by the level of detail and the vividness of the VR.

1.2 Motor rehabilitation after stroke

Stroke is one of the main causes of acquired adult disabilities. Motor impairments following stroke are treated mostly with physical and occupational therapy. The goal is to enhance cortical plasticity and motor (re)learning to restore motor function and to acquire coping skills. Traditional therapy approaches focus on peripheral sensorimotor stimulation using active and passive movements of the affected limb. Within these approaches, practice is the most important factor for learning motor skills and a combination of repetitive and variable movement execution is required (Carr & Shepherd, 2010). Intensive training needs high patient motivation and adherence, which is often difficult to achieve with neurologic patients due to rather high demands for little progress. Informing the patients about their performance and the overall rehabilitation progress therefore is an important feature of practice. Using virtual rehabilitation, this challenge can be mitigated due to the possibility to include performance information in a motivating game experience.

Recent therapy approaches focus on central sensory stimulation of the impaired brain areas and make use of a neurologic mechanism, which activates cortical motor areas by observation or imagination of movements. This allows patients after stroke to activate neuron pathways similar to those recruited to execute movements that they are physically not able to perform. Though details about the underlying cortical mechanism are still under debate, the effectiveness of observing movements in a mirror for motor learning after stroke has been proven (Thieme et al, 2012). Virtual reality systems can replicate and even exceed the capabilities of a traditional optical mirror and produce a stronger illusion of actions for central sensory stimulation (Regenbrecht et al, 2011; Hoermann et al. 2012).

2. INFLUENCING THE EXPERIENCE OF PRESENCE WITH VIRTUAL FEEDBACK

Only limited evidence about features of the VR design for specific rehabilitation effects can be drawn from the literature today (Ferreira dos Santos et al, 2013; Laver et al, 2011). So far no design standards have evolved. Furthermore the applied VR-systems are often considered as a whole technology and not examined in detail during clinical studies, which makes it hard to draw conclusions about the individual design features. However a need for shared design considerations has been stated before and research towards this has been presented by Doyle et al. (2011). Virtual rehabilitation systems provide different types of feedback to the patients. The features of a virtual environment can be separated into distinct groups of feedback. Each of these groups corresponds primarily to a certain presence dimension (Table 1). The three types of feedback will not always be used in virtual rehabilitation systems, but usually they will be implemented to enable a complete game experience.

Table 1. *Types of feedback with their corresponding presence dimension*.

Type of Feedback		Presence dimension
Movement visualization	<—>	Spatial presence
Performance feedback	<—>	Involvement
Context information	<—>	Realness

2.1 Movement visualization

The patients are represented in VR by means of movement visualization, where motor actions are captured and transferred to a graphical object that is synchronously animated. In many cases this object will take the form of an anthropomorphic avatar that is observed from a first- or third-person perspective. However, fictive or abstract objects can also be used. In order to orient themselves in the virtual world and to manipulate objects, patients need to identify with the movement visualization. Since the action potential of the environment is experienced through this representation, spatial presence will be evoked when the patients are able to enact their intentions with the movement visualization. The observation of movement visualization in virtual rehabilitation systems can have a direct effect on motor learning since it can lead to central stimulation of cortical motor areas. Neurophysiological studies have shown that observing virtual limbs' movements stimulates cortical activity similar to the observation of real limbs in a mirror (Dohle et al, 2011). It has been postulated that observation of virtual limbs can facilitate the functional reorganization of the neuronal systems directly or indirectly affected by stroke (da Silva Cameirão et al, 2011). Thus an additional motor learning effect may be achieved when performing and observing movements during training. We furthermore postulate that the experience of spatial presence modulates central stimulation of motor areas during observation of movement visualizations. When experiencing spatial presence, the subject attributes the observed virtual motor actions to itself and corresponding cortical areas will be stimulated. We hypothesize a positive correlation between spatial presence and central stimulation. Therefore spatial presence is of high importance for motor learning in virtual rehabilitation.

2.2 Performance Feedback

Performance feedback is usually considered one of the key features increasing the involvement in virtual environments. During the treatment, patients have to accomplish tasks and when they are successful they gain points or proceed to a more difficult level. The task as well as the points or level will be visualized in some way in order to add meaning to the patient's exercises and inform them about their progress. In terms of its relevance for motor learning, performance feedback can be further differentiated into knowledge of performance (KP) and knowledge of results (KR) (Carr & Shepherd, 2010). In traditional therapies, feedback is often given in terms of KP, leading to an internal focus on the correct limb positions and movements during task execution. However, Wulf (2007) demonstrated that an external focus on the effects that the trained movements should have in the environment is more effective for motor learning. Thus performance feedback should also focus on providing KR. Virtual environments are well suited to provide both, information about the performance and about the results, within a game experience. In this way performance feedback can be regarded as a motivational factor and may foster the patients' adherence to the training. By means of performance feedback, the attention of the patients will be drawn towards the VR and, assuming the patients are willing to succeed in the game, will increase their engagement and involvement. Thus the presence dimension of involvement is linked with the effectiveness of performance feedback by motivating and engaging the patients.

2.3 Context information

Finally context information will be displayed that pictures the virtual world. This information may resemble a naturalistic place or a fictive environment in which the patients' representative and the tasks are conceivable. Background objects and animations give the VR system the impression of a real environment that is not just a technical artefact for therapeutic purposes. Atmospheric sensory stimuli in the form of sounds can add to the vividness of the experience. An important goal of therapeutic treatment is the transfer of learned behaviour to everyday activities, which patients should be confident enough to perform. Virtual environments can display real world contexts and objects used in every day tasks so that the patients can associate the learning with situations from their daily life. The realness presence dimension relates to this kind of vividness of a VR environment. Depending on the treatment approach, virtual rehabilitation systems may display various types of contexts, naturalistic or fictive. However in each case the realness presence dimension will be determined by the amount and coherency of the provided context information and thus affect how well the therapy system establishes a real experience. If an everyday task should be learned the realness dimension may even point towards the possibility of transferring the training situation to daily life.

3. EXAMPLE OF PRACTICAL APPLICATION

A previous study tested the hypothesis that presence is important for motor learning (Schüler et al, 2014). The Abstract Virtual Environment for Stroke Therapy (AVUS) was used for the treatment of 5 upper-limb hemiparetic patients. The system visualizes movement in an engaging way with different levels of abstraction (see Fig. 1).

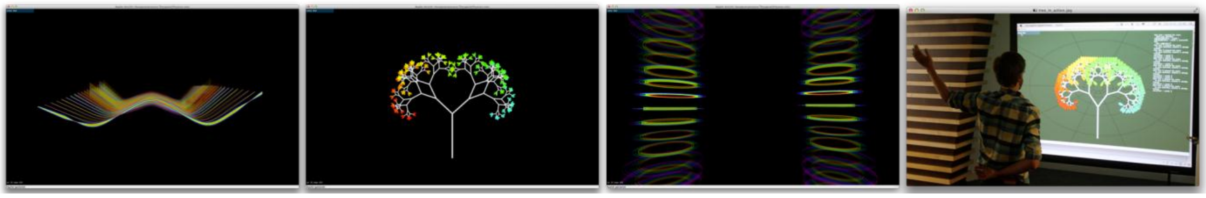

Figure 1. *Movement visualization with the AVUS system.*

AVUS is based on the assumption that observing abstract visualization of movements supports spatial presence and thus central stimulation of motor areas. The results of the preliminary study point towards the soundness of this hypothesis, by showing a suggestive correlation between the experienced sense of presence and the rehabilitation outcome as measured with a modified version of the Igroup Presence Questionnaire (Schubert et al, 2001) and the Fugl-Meyer motor assessment.

4. DISCUSSION

With this article we introduced a conceptualization of virtual rehabilitation systems that distinguishes between three types of feedback and attributed these to three presence dimensions. We suggested how the feedback types and presence dimensions may aid motor rehabilitation after stroke. We presented theories and preliminary study results that point towards the importance of presence for virtual rehabilitation and support our hypothesis that spatial presence modulates central stimulation of motor areas when observing movement visualizations.

Some practical implications can be drawn from our conceptualization. Movement visualization seems to play an important role for motor rehabilitation and should therefore be designed with special caution. While anthropomorphic shapes are used predominantly, there is also scientific rational to use more abstract forms and objects in order to develop a strong sense of spatial presence (Schüler et al, 2014). Future research should focus on clarifying the effects of movement visualization on the experience of presence and motor learning. Some kind of performance feedback is incorporated in most virtual rehabilitation systems. However since involvement in a VR-experience requires concentration, performance feedback should not be overloaded or distract the attention of the patients. Moreover what is judged to be motivating feedback is dependent on personality traits. This type of information should therefore be made adaptable. With regard to context information, the provided information should place the treatment in an appropriate context and allow the patients to have an optimized experience of the VR. Even though each of the three feedback types individually is suggested to have an influence on motor learning or transfer; combining them together will probably be most effective for therapeutic VR applications. Therefore we assume that a consideration of all interrelationships between feedback types and an optimized support of the sense of presence in the virtual environment is important for a holistic realisation of motor learning.

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5. REFERENCES

Carr, JH, and Shepherd, RB, (2010), *Neurological rehabilitation: optimizing motor performance* (2nd ed.), New York: Churchill Livingstone.

da Silva Cameirão, M, Bermúdez i Badia, S, Duarte, E, and Verschure, PF, (2011), Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke, *Restorative neurology and neuroscience*, 29(5), 287–298.

Dohle, C, Stephan, KM, Valvoda, JT, Hosseiny, O, Tellmann, L, Kuhlen, T, … Freund, H.-J, (2011), Representation of virtual arm movements in precuneus, *Experimental Brain Research*, *208*(4), 543–555.

Doyle, J, Kelly, D, and Caulfield, B, (2011), Design considerations in therapeutic exergaming, In *5th Int. Conf. on Pervasive Computing Technologies for Healthcare*, 389–393.

Ferreira dos Santos, L, Schmidt, H, Kruger, J, and Dohle, C, (2013), Visualization of virtual reality neurological motor rehabilitation of the upper limb – a systematic review, In *Int. Conf. on Virtual Rehabilitation (ICVR)*.

Hoermann, S, Franz, EA, and Regenbrecht, H, (2012), Referred Sensations Elicited by Video-Mediated Mirroring of Hands, *PLoS ONE*, *7*(12), e50942.

Laver, KE, George, S, Thomas, S, Deutsch, JE, and Crotty, M, (2011), Virtual reality for stroke rehabilitation, *Cochrane Database of Systematic Reviews*, (9), Art. No.: CD008349.

Lombard, M, and Ditton, T, (1997), At the Heart of It All: The Concept of Presence, *Journal of Computer-Mediated Communication*, *3*(2).

Regenbrecht, H, Franz, EA, McGregor, G, Dixon, BG, and Hoermann, S, (2011), Beyond the Looking Glass: Fooling the Brain with the Augmented Mirror Box, *Presence: Teleoperators and Virtual Environments*, *20*(6), 559–576.

Riva, G, Waterworth, JA, Waterworth, EL, and Mantovani, F, (2010), From intention to action: The role of presence, *New Ideas in Psychology*, 29(1), 24–37.

Schubert, T, Friedmann, F, and Regenbrecht, H, (2001), The Experience of Presence: Factor Analytic Insights, *Presence: Teleoperators and Virtual Environments*, *10*(3), 266–281.

Schüler, T, Drehlmann, S, Kane, F, and von Piekartz, H, (2014), Presence and motor rehabilitation in an abstract virtual environment for stroke patients, In *Proceedings of Presence Conference 2014*.

Thieme, H, Mehrholz, J, Pohl, M, Behrens, J, and Dohle, C, (2012), Mirror therapy for improving motor function after stroke, *Cochrane Database of Systematic Reviews*, (3), Art. No.: CD008449.

Wulf, G, (2007), Attentional focus and motor learning: A review of 10 years of research, *E-Journal Bewegung Und Training*, *1*, 4–14.