

Special Issue: Virtual Environments and Rehabilitation Guest Editors' Introduction

Mankind constantly struggles and invests enormous amounts of knowledge and resources into various research fields related to everyday life. While these investments sometimes have no noticeable effects, at other times the resulting achievements may exceed all expectations. These technologies and approaches are then often transferred from the original field to other areas, where they continue to flourish. This spill-over effect in research and development has fueled a number of neglected fields that are important for human quality of life, but do not receive a large amount of funding. In a way, this is also the case for virtual reality in neurological rehabilitation.

Virtual reality is often an important part of a larger rehabilitation setup that offers rich multimodal stimuli and direct dynamic interaction between the human and a smart machine. As such, it has greatly benefitted from developments in other fields. For instance, cheap camera-based systems for the measurement of body kinematics, such as the Nintendo Wii or Microsoft's Kinect, were first developed for the computer gaming industry, but have recently also become popular for training and rehabilitation at home. Furthermore, simple mobile accelerometers and inertial measurement units are becoming very affordable, leading to the rise of diverse sensory systems, and also special aids for the elderly.

An increasing number of applications employ visual, acoustic, or tactile haptic cues for real-time feedback, with the purpose of challenging or motivating the user during exercise and physical therapy. In virtual reality applications, for instance, measured patient activity such as limb or whole body movement patterns can be displayed on the screen, providing realistic information to the user. However, interaction options that would be appropriate for healthy subjects may not be appropriate for patients, as the two groups differ with respect to their

cognitive and motor capabilities. While some aspects related to challenge and motivation may not be affected by neurological conditions, the way the subject interacts with the environment must be reconsidered when tasks are optimized for a patient population.

People using virtual reality applications tend to respond realistically to the stimuli that they encounter. This natural behavior could be exploited to construct more efficient therapy regimes applying virtual environments. Virtual reality technologies could increase motivation, enabling the patient to train longer and more often while also automatically adjusting the difficulty level of the tasks and providing physical and verbal instructions to the user. All these possibilities have great potential for motor rehabilitation and could lead to improvements in overall motor function. Users would be able to have fun and enjoy engaging in therapies while the therapists and rehabilitation robots would be able to obtain information about the patients' potential emotional or cognitive stress, discomfort, boredom, lack of motivation, or excessive physical demands. These are the keys to adequate human performance levels in future high-tech rehabilitation.

The papers presented in this special issue vary with respect to the rehabilitation target groups and technologies applied to them. Target groups range from patients with neurological and/or cognitive impairments to patients with orthopedic lesions. Many different methodologies are presented employing different audiovisual display technologies to render virtual environments, including, for example, narrative information, or using robotic devices to provide haptic feedback to the subject. Applications include the training of arm movements or gait for hemiplegic patients after stroke, cognitive training of patients suffering from dementia, training of orthopedic patients after joint injury or amputation, and novel neuropsychological assessment methods.

Mihelj, Novak, Milavec, Zihelr, Olenšek, and Munih present a novel multimodal virtual rehabilitation environment that aims at training stroke patients to perform certain motor tasks including cognitive challenges, while maintaining a high level of motivation. Visual and auditory feedback provides the relevant task-related environmental information, voice instructions, sound, music, and further features. The haptic modality generates tactile information related to the environment and provides various modes of assistance for the patient's arm movements. The scenario was evaluated and successfully tested with 16 stroke patients.

Also intended to support motor training of disabled patients is the work of Yano, Tamefusa, Tanaka, Saito, and Iwata, who describe the development of a gait rehabilitation system with a locomotion interface for exercising stair climbing. The interface consists of 2-DOF manipulators equipped with footpads. These can move the patient's feet while his or her body remains stationary. The footpads follow the prerecorded motion of the feet of healthy individuals. In this study, two control modes of stair climbing are presented. Comparisons were made between the modes for healthy individuals and a hemiplegic patient after stroke.

Raspelli and colleagues present a VR-based neuropsychological assessment tool that can be applied to stroke patients as well as to elderly people with age-related cognitive decline. The purpose of their study is to establish ecological validity and initial construct validity of the VR version of the multiple errands test as an assessment tool for executive functions. The VR-based assessment is performed in a shopping mall-like setting, where items can be bought and information obtained. The tool was evaluated on stroke patients, healthy young participants, and healthy older participants. The virtual multiple errands test allowed Raspelli and colleagues to distinguish between clinical and healthy populations as well as between the two age control groups.

Yamaguchi, Foloppe, P. Richard, E. Richard, and Allain developed a dual-modal VR platform for the training of everyday cooking activities in patients with Alzheimer's disease and established its value as a training tool for everyday activities. Two patients with Alzheimer's disease and two healthy elderly controls were tested. It could be shown that patients performed

worse than controls before the training, but that they reached a level of performance similar to that of the controls after a short training session, regardless of the learning method employed.

Another application dedicated to the training of patients with cognitive deficits is presented by Moya, Tost, and Grau. They describe a graphical narrative editor that can be used for the design of serious games. The system is addressed to neuropsychologists and aimed at providing them an easy, user-friendly, and fast way of specifying the therapeutic contents of the rehabilitation tasks that constitute the serious games. The editor takes as input a description of the virtual task environment and the actions that patients are expected to do. The output of the system is a complete description of the task logic. A 3D game platform was designed that provides the editor with a description of the 3D virtual environments and that translates the task description created in the editor into the task logic.

This special issue also includes two publications that have been applied to patients with orthopedic disorders. In their paper, Nilsson, Serafin, and Nordahl present the design and implementation of a wobble board prototype intended to increase motivation during the training of ankle joint movement. This prototype enables users to control a game, thus allowing them to perform the necessary exercises while playing. The efficacy of the training was assessed, and 40 individuals took part in a quantitative evaluation study performed in order to determine whether the prototype could potentially provide the required motivation. It was concluded that the prototype does ensure correct ankle training and that the act of playing was experienced as intrinsically motivating by most of the test subjects.

The second orthopedic application is presented by Davoodi and Loeb. For upper limb amputees, learning the control of myoelectric prostheses is difficult and challenging. To produce smooth and humanlike movements, the user must learn to produce multiple neural commands with precise amplitude and timing. To support such training for amputee users, a realistic virtual environment has been developed consisting of a physics-based target shooting game. The users' neural commands such as EMG, cortical neural activity, or voluntary movements of the residual limbs can be used to control the movement of a simulated prosthesis to point and

shoot at virtual targets. In addition to the audiovisual feedback, the game provides reaction forces on contact points that can be used to drive haptic displays.

Last but not least, Haringer and Beckhaus present a study in which users experience 30 selected means of physiological or facial expression and rate their qualitative emotional impact using a novel rating method. They found that different means of expression can be used to elicit many diverse emotions which were surprisingly consistent among the healthy test subjects. These results enable new ways to make virtual environments more interesting and emotionally engaging, especially over a longer period of time, opening new possibilities, for

example, to increase the motivation for long, stressful, and fatiguing neurorehabilitation training.

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