The Combined Effects of Adaptive Control and Virtual Reality on Robot-Assisted Fine Hand Motion Rehabilitation in Chronic Stroke Patients: A Case Study

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Robot-assisted therapy is regarded as an effective and reliable method for the delivery of highly repetitive training that is needed to trigger neuroplasticity following a stroke. However, the lack of fully adaptive assist-as-needed control of the robotic devices and an inadequate immersive virtual environment that can promote active participation during training are obstacles hindering the achievement of better training results with fewer training sessions required. This study thus focuses on these research gaps by combining these 2 key components into a rehabilitation system, with special attention on the rehabilitation of fine hand motion skills. The effectiveness of the proposed system is tested by conducting clinical trials on a chronic stroke patient and verified through clinical evaluation methods by measuring the key kinematic features such as active range of motion (ROM), finger strength, and velocity. By comparing the pretraining and post-training results, the study demonstrates that the proposed method can further enhance the effectiveness of fine hand motion rehabilitation training by improving finger ROM, strength, and coordination. **Key Words:** Stroke rehabilitation—robot assisted therapy—assist-as-needed control—virtual reality—rehabilitation gaming system—clinical assessment.

Introduction

Stroke can result in paralysis, speech impairment, loss of memory and reasoning ability, coma, or even death.[1] Complete or partial loss of movability in an upper extremity (UE) is the most commonly reported impairment after suffering a stroke, which can hinder the performance of activities of daily living (ADLs) and significantly undermine the quality of life (QOL) of the stroke patient.[2] Recent neuroplasticity studies indicate that a highly repetitive and task-specific training may induce changes in the brain, and this response can be optimized if the task is challenging enough.[3] This approach holds promise for the improvement or even recovery of the affected motion skills. However, conventional therapies (CTs) such as physical and occupational therapy can be time-consuming and labor intensive, requiring long training sessions and incurring high costs. Moreover, it is difficult to effectively evaluate the effectiveness of CTs quantitatively and objectively. Robot-assisted therapy (RT)[4] can provide a highly repetitive movement training and overcome the shortcomings of CTs through the reduction of associated labor and the offer of an accurate, automated movement control and the quantification of rehabilitation performance.[5]

Multisensory feedback has been proven to be critical in re-establishing the neural pathways damaged by stroke and closing the sensor motor loop.[6] Virtual reality (VR) technology has recently been widely used in the field of augmented stroke rehabilitation. VR allows users to interact with a multisensory simulated environment and receive real-time feedback on performance, thus allowing patients to correct their motion. This, in turn, can

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facilitate repetition, intensity, and task-oriented training, all of which promote voluntary active motion. Therefore, VR-based RT offers the potential to specifically promote and/or enhance functional movement recovery.[7]

VR systems can provide safe, ecological, and individualized 3-dimensional environments where patients can perform specific actions to achieve a goal. Another advantage of a VR intervention is that patients can perceive such interventions as enjoyable exercise games rather than treatment methods and, thereby, increase motivation and treatment compliance.[8] VR can also be used as an assessment method by recording and objectively measuring the performance of patients and their behavioral responses within the virtual world. VR-based RT thus has the potential to utilize motor learning principles in relation to task-oriented training. However, the intensity and dose–response aspects of a VR game–based intervention training with evidence-based efficacy and clear objectives and outcomes need to be further determined.[9]

The aim of this study was to further evaluate the effectiveness of the developed VR-based RT treatments with an adaptive control method deployed in a robotic training device. In addition, the study explores more effective methods to transform the achieved improvements to the performance of ADL tasks in real life. Special attention is paid to fine hand motion rehabilitation, which involves small, precise, and coordinated movements of the fingers and requires the integration of muscular, skeletal, and neurological functions. This is because fine hand motion is vital for more delicate ADL tasks such as eating, drinking, and personal hygiene and is necessary for the improvement of the QOL of stroke patients.

Materials and Methods

RT Platform

In this study, a 5 degrees of freedom hand rehabilitation robotic device named Amadeo (Tyromotion GmbH, Graz, Austria)[10,11] was used as the experimental platform. Amadeo (Tyromotion GmbH) can provide position-based passive and active assistive training modes that emphasize the flexion and extension of each finger. The moving finger slides are attached to the fingers using a small magnetic disc and an adhesive tape for connection to the robot. The slides then transfer, bend, or stretch movements to the fingers. The VR-based RGS is implemented with Amadeo (Tyromotion GmbH), which is composed of a finger rehabilitation robot and a PC with LCD displaying the virtual scenarios in front of the user as shown in Figure 1.

The major limitation of Amadeo's (Tyromotion GmbH) standard training protocol is that it provides position control with constant assistive force intensity regardless of the actual need of the patient. In clinical practice, patients with different levels of active mobility skills require various levels of assistive support. Also, even for the same patient, this constant assistive force intensity can be excessive to that required for the movement of the finger. As a result, the patient may end up following the finger slides passively, which makes the training task less challenging and compromises the effectiveness of the training. In order to achieve optimal training results and to reduce the required training sessions and associated costs, a reinforcement learning neural network–based AAN adaptive control was designed and validated through computer simulation and experimental work. The notion of the AAN control method is to provide exact assistive force intensity along the intended motion trajectory only when it is needed, thus keeping the training challenging and engaging. This is achieved by observing the force and position feedback state at the current time-step and making predictions of the next time-step state based on the feedback data. A detailed design and online learning process of the proposed AAN control method can be found in Huang et al.[12]

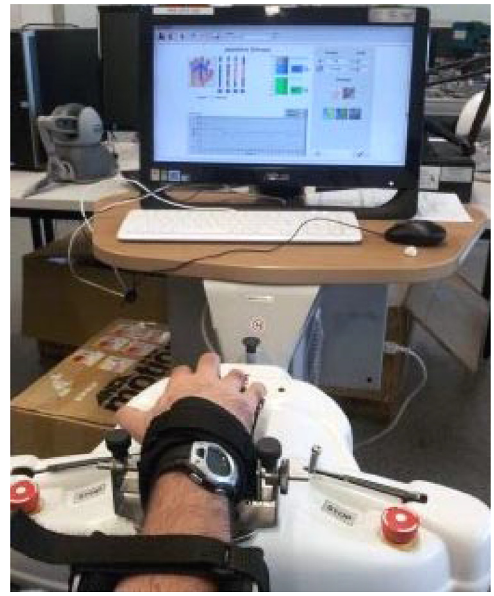

Figure 1. *Training conducted on a stroke patient using Amadeo.*

Participant

Considering the final evaluation, comparisons and conclusions will be based on the performance of the patient during clinical tests; the condition of the subject before the study may affect the outcome of the rehabilitation process. Thus, it is important to set unified requirements for recruited patients to ensure that they start with similar conditions. The Fugl-Meyer Assessment (FMA) and the Motor Assessment Scale (MAS) were used to assess patients' abilities during the evaluation sessions. In order to maintain consistency, we defined the following inclusion requirements for the recruited subjects:

1) Age range: 50-75 (patients around the same age were preferred).