Self-Avatar Motion Retargeting for Virtual Reality Post-Stroke Rehabilitation Therapy

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ABSTRACT

Post-stroke rehabilitation therapies in Virtual Reality have shown to be a valid alternative to traditional non-virtual therapies. In rehabilitation therapies based on induced movements, the kinesthetic illusion induces a feeling as if the individual's body movements were wider than the actual during the exercise. This rehabilitation therapy approach in virtual reality is still novel and many aspects are unclear. Our research focuses on the investigation of the user's perception of the altered virtual body movements in virtual reality, to define the best rehabilitation strategy.

CCS CONCEPTS

• **Applied computing** → *Interactive learning environments*; • **Human-centered computing** → **Virtual reality**; • **Computing methodologies** → **Virtual reality**.

KEYWORDS

Virtual Reality, Sense of Embodiment, Visuomotor Illusion, Motion Retargeting, Post-stroke Rehabilitation

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1 INTRODUCTION

Stroke is one of the major leading causes of disability worldwide [11]. The main issues related to post-stroke patients are cognitive, motor, functional and emotional sequelae, whose impairments restrict patients' daily living activities [7]. Since stroke-related motor impairments are persistent and difficult to treat, several rehabilitation approaches have been developed to recover from illness and regain a normal lifestyle. To be effective, stroke rehabilitation therapies should be intense and prolonged over time [13], yet this is not always possible because of several reasons, including the high cost of the treatment, the inability to travel and the low number of available therapists [7]. To address these issues, several studies proposed solutions in which patients can access therapy without the full supervision of a therapist in person [13]. These approaches were found to be as effective as the standard face-to-face ones. In particular, the introduction of virtual reality technologies in rehabilitation was shown to be a valid option (See Palacios-Navarro *et al.* for a review [16]).

According to Shermann [18], virtual reality (VR) can be defined as a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world). The introduction of VR technology in the rehabilitation scenario has several advantages. First, virtual reality makes it possible to develop customized environments, according to the individual needs of patients and therapists [3], allowing the implementation of treatments in a controlled environment, in which any external and potentially dangerous intervention is excluded. For instance, VR allows patients to perform basic daily activities in a safe environment, increasing engagement and motivation [13]. Second, the ability to design customized exercises increases patient satisfaction and engagement [13]. As traditional rehabilitation exercises involve tedious and repetitive tasks, patients tend to lose motivation, which can lead to a reduction in the rehabilitation intervention or effectiveness. Yet, in VR is possible to maintain a high level of motivation and enjoyment by designing engaging exercises [23]. Third, using a VR device makes it possible to record user behavior during therapy sessions. This feature encourages asynchronous rehabilitation without the direct supervision of the therapist and helps the evaluation of the performance of the patient and progress over time [3].

In a virtual reality scenario, users can be represented through a virtual body, called self-avatar, that reproduces the movements of their physical body. The effectiveness of the relationship between the self-avatar and the physical body in Virtual Reality requires the VR system to induce the so-called Sense of Embodiment. According to the definition given by Kilteni *et al.* [10], the Sense of Embodiment (SoE) refers to a set of sensations related to having, controlling and processing a virtual body (or a part of it) as if it is ours. Typically, a self-avatar mimics the movements and behaviors of the physical body. However, virtual body movements can be altered, creating a gap between the self-avatar movements and the physical body ones (called motion retargeting) [2, 8, 22], without making users aware of it. The ability to accurately reproduce and alter users' movements in a VR scenario opens up a wide range of advantages over conventional approaches to rehabilitation.

Typical virtual reality rehabilitation therapies on upper and lower limbs leverage approaches such as Constraint-induced movement therapy (CIMT) in which the induced motion is given with an external robotic tool [4], and mirror-therapy exercises, in which

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the movement of the impaired limb is simulated throughout the mirroring of the healthy one [1, 14]. Another standard post-stroke rehabilitation therapy that proved to be effective is the Kinesthetic Illusion Induced by Visual Stimulation (or KiNVIS) [15], in which the actual patient's arm is covered by a screen that plays a recorded movie of a moving hand. With this approach, the seen and actual movements of the body differ, producing an illusion of kinesthesia that leads to an improvement of individual motor function (visual-motor illusion). The ability of a virtual reality system to retarget self-avatar movements makes this technology a valid option for post-stroke rehabilitation therapy based on induced motion illusion. However, according to the authors' knowledge, this rehabilitation approach in virtual reality is still novel. The technology's ability to accurately alter self-avatar movements while hiding the physical body ones may determine the effectiveness of this rehabilitation approach in virtual reality. In this scenario, it is crucial to investigate how much difference between the virtual and physical body optimizes the induced movements and the rehabilitation outcome without affecting the Sense of Embodiment. It is important to understand how much difference between the virtual and physical body maximize the induced movements without affecting SoE. Furthermore, introducing a gradual and dynamic motion retargeting variation on the self-avatar movements could improve the rehabilitation results.

2 RELATED WORKS

Since the rubber hand illusion was proposed by Botvinik *et al.* [5], several works focused on the understanding of the SoE towards fake and virtual limbs (See Riemer *et al.* for a review [17]). In recent years, multiple projects focused on the user's perception of virtual body movements.

Soccini *et al.* [19, 22] defined the induced finger movements effect as the involuntary physical hand motion resulting from the introduction of external movement (alien motion) on the self-avatar fingers. These studies showed that the introduction of an alien movement does not nullify SoE. Moreover, the induced movements take place only when the virtual body is embodied. Gonzales Franco [9] defined the self-avatar follower effect as the involuntary alteration of the physical body movements to mimic the virtual body ones. In particular, the study showed how the introduction of motion retargeting applied in self-avatar movements makes users follow the self-avatar itself, leading to a drift of the physical body. Then, results suggest that the defined follower effect and SoE are greater when the alteration of the movements was introduced gradually, rather than instantaneously. These results were confirmed by Burin *et al.*, whose study showed how retargeting of the self-avatar movements causes the user's physical motor performance to be attracted toward the embodied virtual body movements [6].

While the mentioned works focused on understanding how user's physical body and the SoE are affected when external movements are introduced to the self-avatar, other studies investigated the user adaptation to new self-avatar behavior. Soccini *et al.* [21] explored user's ability to adapt to frequent and abrupt changes in self-avatar movements. The results suggest that users can adapt to the new self-avatar behaviors without compromising the SoE, even when the alterations occur frequently over time.

Lilija *et al.* [12] presented a VR system where the position and pose of the user's hand are adjusted to align more closely with the target movement. Motion retargeting introduces a mismatch between the actual position of the user's physical hand and its virtual representation. Although the results indicate that self-avatar movement correction enhanced motor learning and short-term retention of the trained movements, the optimal amount of alteration in self-avatar movements to maximize learning outcomes remains unclear. In all the presented works, despite the retargeting of the self-avatar movements, the Sense of Embodiment persists and is not nullified.

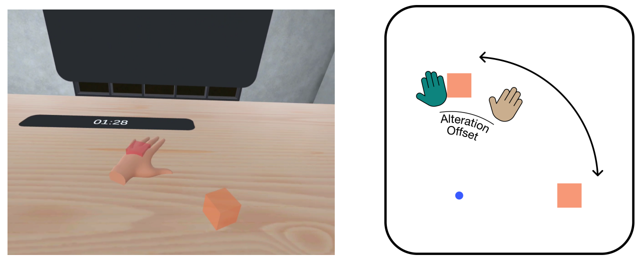

Figure 1: User point of view during the experimental exercise (Left) and the corresponding motion retargeting scheme (Right) in Soccini *et al* [21]. The orange cubes represent the target movements, the pink hand corresponds to the user's physical hand, and the green hand depicts the retargeted position of the self-avatar hand.

3 PROJECT OVERVIEW

In a virtual reality rehabilitation scenario, where self-avatars are used as a guide to lead the users, the difference between virtual body and physical behavior defines the possible induced movements [20]. However, according to the authors' knowledge, the Kinesthetic Illusion Induced by Visual Stimulation rehabilitation therapies [15] in virtual reality is still novel.

So far, we already investigated users' perception of frequent changes in self-avatar movements and their ability to adapt to the new virtual body behavior [21]. To understand how users can adapt to frequent changes in self-avatar movements, in this study participants were asked to flex and extend their left arm toward two virtual targets, following the rhythm marked by a metronome, while the self-avatar motion retargeting pattern dynamically changed (Figure 1). The analysts of the performance suggest that users can quickly adapt to new self-avatar retargeted movements without affecting the Sense of Embodiment.

However, to consider this technique a valid and effective option for post-stroke rehabilitation therapy, it is important to further investigate how motion retargeting and user adaptation to these new behaviors are linked. To achieve this goal, several unclear aspects need to be investigated:

- there are still no clear criteria to determine which amount of alteration of the self-avatar's movement could optimize the exercise outcome and the rehabilitation effects. A great motion alteration could lead to a significant rehabilitation outcome, but it may reduce or nullify the SoE. On the other hand, a small alteration of the self-avatar behavior could not affect the Sense of Embodiment, but the induced effect may not be obtained.

- in current rehabilitation therapies based on the KiNVIS approach [15], the amount of alteration between the virtual and physical body is stable and does not change throughout the exercise. The introduction of a dynamic motion retargeting pattern during the rehabilitation process may be more effective. Additionally, it's important to understand how the self-avatar behavior should vary to increase the induction of motion without affecting the SoE;
- it is not yet clear how long the virtual reality rehabilitation exercises should last and how frequently the self-avatar behavior should change.

We will investigate these issues starting from the experimental design from our previous work [21], in which different retargeting patterns and interactions with objects will be included. In particular, while the previous work only focused on specific movements (flexion and extension of the arm), we are currently developing a VR app that introduced the self-avatar motion retargeting of all the movements of the arms of the users, without restriction on the physical motion (Figure 2). Moreover, to increase the user's engagement, the movement tasks requested in the previous experiment could be replaced with interaction-based tasks, such as the know game "whac-a-mole", in which players use a mallet to hit fake moles that randomly pop up. The KiNVIS rehabilitation approach only consists in enhancing user's movements. However, in a rehabilitation context, some movements could be dangerous for the patient. Since users unintentionally tend to follow self-avatar movements, the VR application could implement two different motion retargeting patterns: one for enhancing user movements and another for altering the self-avatar motion to avoid potentially dangerous actions.

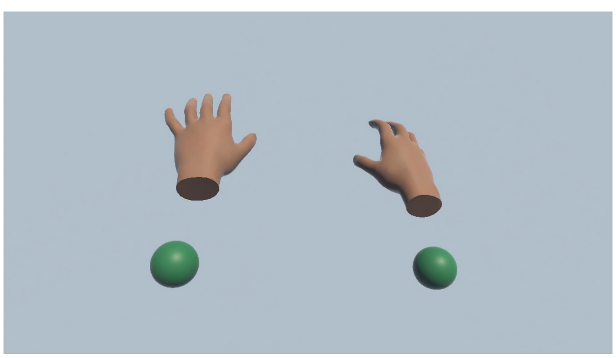

Figure 2: Example of motion retargeting in a VR application. The green spheres correspond to the user's real hand position, while the pink hand represent the altered position of the self-avatar.

4 CONCLUSION

Thanks to the rapid growth and improvement of digital technologies, virtual reality systems and applications are used in several areas, including medical rehabilitation. While in the last few years several studies regarding virtual reality rehabilitation therapies have been carried out, there is still much work to do to make these approaches widely available and more effective. Latest developments in VR offer the opportunity to provide users with virtual bodies, and understanding how self-representation and user's kinetic reaction to altered self-avatar movements work becomes essential to give a solid contribution to the evolution of virtual therapy.

While the presented Ph.D. project primarily focuses on post-stroke rehabilitation, the investigation of self-avatar motion retargeting is important to enhance VR interaction and user experience for a broader range of users. For example, some user may face limitations in their physical spaces or encounter motor disabilities that reduce their movement capabilities. Dynamic self-avatar motion retargeting could be employed in different contexts, such as interaction within a virtual environment or locomotion. In this scenario, exploring self-avatar motion retargeting techniques is essential to guarantee the extensive accessibility of VR technology. By improving and incorporating motion retargeting methods, VR experiences can be customized to the user's needs, making this technology more inclusive and accessible for all.

DOCTORAL PROGRAMME DETAILS

Alessandro Clocchiatti is currently enrolled in the second year of the PhD program in Computer Science at University of Torino, in Italy. His supervisor is Professor Agata Marta Soccini. This PhD program lasts three years and the expected completion date is the end of 2025. He previously attended a doctoral consortium only once, during the CHItaly conference held in Torino (Italy) in 2023.

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