ABSTRACT

Stroke is a neurological disorder that is defined as “a clinical syndrome, of presumed vascular origin, typified by rapidly developing signs of focal or global disturbance of cerebral functions” according to the World Health Organization. The deferred cerebral function is often manifested in the form of visual, motor and speech deficits along with paralysis making the disorder a common cause of death and the fourth leading cause of disability worldwide. Hemiplegic stroke is one of the major contributors to the disability that often adversely affects the upper and lower limbs of the patients which are contralateral to the hemisphere of the brain where the lesion has occurred. Reduced muscle strength, spasticity in limbs, reduced coordination in arms and legs and lack of mobility in limbs are few of the common symptoms that are seen on the paralyzed side of the hemiplegic stroke survivors. The motor dysfunctions in one’s upper limbs can affect the grip ability and hand coordination skill of a stroke survivor that in turn often limits the ability to independently execute daily living tasks, such as brushing of teeth, drinking from a glass, etc. To address such deficits, these patients are often prescribed rehabilitation exercises administered by expert clinicians. The therapeutic regime follows a standard protocol that starts with the assessment of a patient’s residual ability in the limbs, such as in one’s upper limb. Following the assessment, the patient is asked to undergo rehabilitation exercise whose intensity is adjusted to suit the residual capability of the patient. To alter the intensity of the exercise during the process of rehabilitation, the therapist intermittently changes the challenge level of the exercise based on the rehabilitation outcomes. For this, the therapist evaluates the patient’s capability by using some standardized scales. For example, the standardized scales are Modified Ashworth Scale (MAS) for measuring the spasticity in the arm, wrist and fingers of the upper limb, Fugl-Meyer Assessment (FMA) for measuring the coordination ability in the upper limb, Manual Muscle

Testing (MMT) for measuring the force-producing ability of the muscles, etc. Also, the residual grip strength is measured using portable devices, such as Dynamometers. The evaluation carried out using measures, such as MAS, FMA, MMT, etc. are often subjective in nature and depends to a great extent on the expertise of the therapist doing the evaluation. Again, the measurements using standalone devices e.g., hand grip Dynamometer provide a gross measure of the patient's grip ability without giving any insight into the physiological profile of the patients. Stroke being a neurological disorder, affects one's ability to do a task, such as performing a grip action that can have physiological manifestations. Specifically, the inability to do a grip task is often related to anomalous muscle activation in one's upper limb that can be adversely affected due to changed muscle tone, spasticity, etc. after stroke. Before addressing such a deficit, one needs to quantify the residual ability of a patient. An alternative to quantify the post-stroke disability can be to study the muscle activation pattern during one's grip action. With the advancement in sensing technology, the use of surface electromyogram (sEMG) based monitoring of muscle activation has created an avenue to carry out technology-assisted quantification of residual grip ability after stroke. **Taking advantage of the technology-assisted quantification, I have developed an sEMG-based framework for quantification of residual grip ability of post-stroke patients which is presented as the first objective of my research.** In order to achieve this objective, I have designed and conducted a study with a group of post-stroke patients and monitored the sEMG activation of their upper limb muscles (both antagonist and agonist muscles) during the execution of an isometric grip task. Multivariate Multiscale Sample Entropy (MMSE) based analysis of the sEMG signals was used to compute the interactions between the antagonist and agonist muscle pairs (of the upper limb) and evaluated its possible clinical relevance. The result of the study indicated that the MMSE-based quantification of sEMG activation can be used as an objective measure to quantify residual grip ability in post-stroke patients.

After one's residual ability has been assessed, the patient is often referred to a rehabilitation regime aiming to address various issues related to post-stroke condition, such as grip ability, coordination skill, etc. In this, the patients are exposed to rehabilitation training exercises. The conventional therapeutic rehabilitation exercises aimed to improve the grip ability and coordination skill in the upper limb needs one to undergo repeated exercises, such as using sponge ball and putty along with making flexion, extension, abduction and adduction movements of the arm and elbow joints. These repetitive exercises (spanning across multiple exposures) are generally performed under therapist's supervision and have been proven to be promising. However, the conventional settings with one-on-one therapeutic intervention are often resource-hungry, need the continuous presence of expert therapists, monotonous and lacks in providing one with motivating exercises spanning across multiple exposures. Given these limitations, researchers have been exploring complementary technology-assisted solutions for rehabilitation.

Among the technology-assisted rehabilitation platforms, the robot-based and computer-based (with Virtual Reality (VR) mediated exercises) rehabilitation platforms have gained popularity. In my research, I have chosen the computer-based VR technology for designing individualized and adaptive exergaming platforms aimed towards improving the **Grip ability and Hand coordination skills** of post-stroke patients. In this, I have designed three VR-based exergaming platforms and have investigated the potential of these platforms to contribute to upper limb rehabilitation of post-stroke patients while targeting their grip strength and coordination skill. **Thus, my second objective was to design and investigate the implications of VR-based exergaming platforms augmented with sEMG-enabled biofeedback mechanism on one's grip ability and grip strength. The third objective of my research was to design and investigate the implications of a VR-based performance-sensitive exergaming platform on the coordination ability of post-stroke patients.**

To achieve my second objective, I have designed two VR-based platforms that were capable of providing the sEMG-enabled biofeedback in (1) Uni-Manual and (2) Disintegrated Bi-Manual modes. The target participant pool being hemiplegic post-stroke patients, the first platform was designed to offer audio-visual biofeedback to the patients while they performed a grip task with their affected hand (**Uni-Manual** mode). Here, the audio-visual representation of one's grip strength was provided to the patients. Specifically, one's muscle activation (in terms of sEMG signal) in the paretic (affected) hand was mapped to vary the position of a dynamic VR object on the VR-based Graphical User Interface (GUI). In this, the dynamic VR object was programmed to be displaced and reach different goal levels (challenges) in the VR-based GUI depending on the amount of muscle activation in the affected hand during a grip. In order to facilitate an individualized grip exercise, the difficulty of goal levels was calibrated based on the sEMG activation while a patient did maximum voluntary contraction in the paretic hand during each exposure. Additionally, I have conducted a longitudinal study to provide the post-stroke patients with multiple exposures to the VR-assisted Uni-Manual exercise platform. The results indicated that multiple exposures to the VR-based sEMG-enabled biofeedback platform contributed to the improvement in the grip ability and grip strength of the patients, manifested in terms of (1) VR-based task performance, (2) sEMG activation pattern and (3) clinical measures. Though the results were promising, yet this VR-based platform augmented with Uni-Manual biofeedback mechanism adjusted the task challenge levels depending on the patient's maximum grip strength in the paretic hand. Given the fact that the maximum grip strength in the paretic hand of a hemiplegic patient is less than that of the other hand (non-paretic (i.e., unaffected) hand), deciding the thresholds for the task challenge levels might lead to limiting the rehabilitation outcome. One of the ways to address this is to use their maximum grip strength in their non-paretic hand to decide the thresholds for the challenge levels (considering that the grip strength in the non-paretic hand is larger than that in the paretic hand). Given this alternative, I have designed my second exergaming platform that is targeted to offer VR-based sEMG-enabled biofeedback for grip strength exercise in **Disintegrated Bi-Manual mode**. Here, the audio-visual biofeedback was designed to offer a representation of the muscle activation in both the upper limbs of a patient (i.e., Bi-Manual mode). Though the task was Bi-Manual, the VR-based feedback was offered in a disintegrated manner by demonstrating the muscle activation in both the upper limbs of a user separately thereby eliminating any element of compensatory mechanism (commonly used by post-stroke hemiplegic patients). This featured two dynamic VR objects on the VR-based GUI with each being mapped to the sEMG signal captured from respective individual hand. The Bi-Manual platform was individualized similar to the Uni-Manual platform. For this, the thresholds for the varying goal levels (challenges) of the Bi-Manual platform was adjusted based on the maximum grip strength of the patient in an individualized manner. Specifically, the goal levels were calibrated based on the muscle activation in the non-paretic hand when the patient performed maximum voluntary contraction while making a grip. To evaluate the rehabilitative potential of the platform, I have conducted a study with a group of post-stroke patients who were offered multiple exposures to my platform. The results of the study indicated a potential of this system to improve one's grip ability and grip strength quantified in terms of (1) VR-based task performance, (2) sEMG activation and (3) clinical measures.

To achieve my third objective, **I have designed and investigated the implications of a VR-based exergaming platform on the coordination ability of post-stroke patients.** The platform was programmed to be performance-sensitive i.e., the platform was programmed to vary the task difficulty based on one's performance in the VR-based coordination exercise. The task difficulty of the coordination tasks was defined in terms of the extent of arm flexion and the number of changes in hand orientation required to complete a VR-based task. In this task, the patient was expected to lift his / her arm and maneuver his / her hand in the physical space to sketch patterns in the GUI displayed on the Task computer monitor. Delivering of audio-visual feedback was also a part of the study design. In order to map the arm movement in the physical space to the VR-based GUI, a Kinect Xbox-360 was used. This study involved a usability evaluation in which a group of stroke patients was offered multiple exposures. The results showed that this platform has the potential to contribute to rehabilitation in terms of improving one's (1) VR-based task performance, (2) ability to use tasks of higher difficulty levels after a limited number of exposures. However, given a limited number of exposures, no clinical improvement was noticed. The study with each of the three exergaming platforms ended with a survey to understand the usability of the system by the target group. The results of the survey indicated that the participants were very positive about using the platforms.

To summarize, the outcomes of my research were the design of (1) sEMG-based framework for quantification of residual grip ability, (2) VR-based sEMG-enabled exergaming platform (Uni-Manual and Disintegrated Bi-Manual) and (3) Kinect-assisted Performance-sensitive exergaming platform. Additionally, I investigated the implications of (a) Uni-Manual and Disintegrated Bi-Manual exergaming platforms on the grip ability and grip strength and (b) Kinect-assisted exergaming platform on the coordination skill of post-stroke patients that have been presented in my thesis.