Mirror Therapy Augmentation by EMG-EStim Treatment

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Term Project Report

Abstract

Hand therapy is concerned with treating injuries and conditions, ranging from stroke-induced paralysis to sports-related injuries, affecting the upper extremities. Resultantly, innovations in this field have a great potential to reach a large and diverse audience of people in need. After interviewing a hand therapist and conducting literature reviews, it was found that Mirror Therapy and Electrical Stimulation both work to improve recovery for a range of hand movement conditions. This work presents a study that combines these two treatments through a proposed therapeutic device for subacute stroke patients facing upper extremity paresis. In this single-blind randomized study, subjects undergo either conventional Mirror Therapy alone or with our proposed device multiple times a week for a minimum of three months. Finally, subjects will undergo frequent motor function assessments to determine the rehabilitation potential of our proposed device to effectively reduce upper extremity paresis recovery time.

I. Introduction

In the United States alone, there are approximately 795,000 people annually who suffer from a subacute stroke [1]. Stroke is one of the leading causes of long-term disability, and about 87 percent of those who survive stroke experience reduced mobility including upper extremity paresis [1]. As a result, hundreds of thousands of patients seek treatment from occupational and hand therapists to regain function and control of their affected extremities. Mirror Therapy (MT), previously known for use on amputees in the treatment of phantom limb pain, is now being explored as a common therapeutic modality for increasing functional independence in subacute stroke patients. However, there is a question as to whether another common therapy - electrical stimulation - can be combined with MT to achieve an improved restoration of arm function.

A. Background

Hand Therapy techniques include common approaches from heating, icing, and splinting to more nuanced therapies such as ultrasound and edema control [2]. Therapists curate individual treatment plans based on patient goals, desires, physical state, sources of pain etc. Two common treatment approaches have been identified; bottom up– treating peripheral symptoms first – or top down in which central nervous system (CNS) changes are addressed. However, integrating all forms of the patient's condition from peripheral/CNS symptoms to even emotional and mental states has been shown to be most effective in pain management and recovery [3]. Therapeutic modalities that utilize these different approaches include Electrical Stimulation (EStim) and a relatively new approach called Mirror Therapy.

MT was proposed in 2007 as an intervention for phantom limb pain (PLP) [4]. MT utilizes visual illusion feedback through the motion of a patient's sound extremity reflected in a mirror allowing the patient's brain to perceive movement and simulate motor learning and recovery in their injured extremity [5]. This treatment targets CNS rehabilitation by taking advantage of the body's mirror neuron system (MNS). MNS neurons "mirror action and behavior of others" and fire during observation of motor movements or when an individual themselves performs motor tasks [6]. During MT motor imagery exercises, changes occur in the CNS that result from excitability of the corticospinal motor pathways. This causes strengthening of motor neuron synapses and increased cortical signal conductivity. Thus the patient's brain is mapping their motor movements through neuron excitation and training the affected extremity muscles as a result [6]. In supplement to the physiologic outcomes, MT trains patients mentally providing them with confidence in their own recovery. The role of mental practice in rehabilitation has been explained in several theories, two of the most relevant proposed by Paivio and Van Leeuwen/Inglis. Paivio suggests mental practice triggers motivational components within a patient, enhancing their performance [7]. Similarly, Van Leeuwen and Inglis modified this theory stating mental practice helps patients "focus on specific goals and contributes to a decrease in the depressive state" that many patients experience during recovery [8]. This empowers patients to acquire special skills and promotes generalization of treatment practices into their daily lives. MT is an easy to use and low cost source of therapeutic relief. However, since 2007, most case studies for effectiveness have been on patients suffering from PLP and only recently more studies are coming out with promising results for its effect on other neurological debilitations such as stroke.

While MT focuses on brain activity, electrical stimulation focuses on muscle fiber excitation for a variety of injuries and conditions. Different types include transcutaneous nerve, neuromuscular (NMES), interferential current, iontophoresis and more. Although each slightly different, they generally function to decrease pain and increase circulation and task performance. EStim mechanically targets affected areas by mimicking voluntary contractions at the site to enhance rehabilitation of the muscle. NMES is one of the most common types of EStim used clinically. With one or more active electrodes placed in proximity to muscle motor points, NMES "preserves muscle mass and function during prolonged periods of disuse" and aids recovery and improvement of muscle function [9]. NMES can excite different muscle types favoring both fast and slow motor units. However, the treatment is limited by patient discomfort during use as well as contractile activity occurring in mostly superficial muscle fibers. To deal with some of these limitations, researchers have studied Electromyographic (EMG)-triggered NMES and its effects on upper limb recovery of stroke survivors. When EStim is coupled with EMG signals, clinicians can utilize their patients' own voluntary motor movements to initiate EStim impulses into the affected extremity. This resulted in promising outcomes under the commonly used hand function tests - Fugl-Meyer Assessment and Wolf motor function test - suggesting benefits in the use of coupling EMG with EStim [10].

A recent study on the neurorehabilitation of stroke patients combines the treatment approaches discussed above. They studied the effects of "combining multichannel EMG-triggered stimulation with Mirror Therapy in patients with severe or very severe arm/hand paresis" [11]. The subjects underwent bilateral EMG stimulation for 3 weeks and the treatment group also received Mirror Therapy feedback. They hypothesized that the combination of peripheral sensorimotor feedback and cortical stimulation will enhance benefits of rehabilitation. The treatment group showed significant recovery based on the Fugl-Meyer Assessment concluding that MT as a supplement to EMG triggered EStim enhances a patient's recovery but also made clear that the opposite conclusion cannot yet be made. In continuation with this recent research, we are looking to fill this explicit gap in knowledge - if the inverse relationship of these two therapies holds the same benefits. We hope to study if EMG triggered EStim can thus instead be used as the supplement to Mirror Therapy in order to strengthen the patient both mentally and physically and while also limiting patient pain/discomfort.

B. Overview

From prior studies we know that both EMG-EStim and MT individually are effective therapeutic modalities in the treatment of subacute stroke paresis. Recent research shows that MT as a supplement to EMG-EStim can improve a patient's recovery, more than EMG-EStim treatment can alone. To continue the work in this space, we hypothesize that implementation of EMG-triggered electrical muscle stimulation as a supplement to Mirror Therapy for hand rehabilitation will help patients recover quicker than treatment through Mirror Therapy alone. An interview with a professional hand therapist, discussed in Section II, revealed that the best treatments should prioritize restoring function and avoiding further injury to the patient. In Section III we propose a single-blind, long-term study to observe the effectiveness of a combinatorial MT with EMG triggered stimulation system in improving recovery time for upper extremity paresis compared to MT alone. If what we hypothesize is correct, as discussed in Section IV, our results could influence future work by offering a baseline optimum treatment that can be applied to patients presently or improved through future developments. The results of the study may also enable the widespread implementation of this augmented Mirror Therapy, as will be examined in Section V.

II. Preliminary Results

To learn more about the current state and future of hand rehabilitation, we first conducted an informational interview with an expert. Our interviewer is a certified occupational therapist with a certification in hand therapy; based in California, they've treated a variety of hand ailments for 34 years with nearly half of that time spent operating a privately-owned practice. As we learned from the interview, which was conducted virtually via video conferencing, our interviewer has developed successful treatment plans for hundreds of hand injuries. Resultantly, our interviewer was used to working quickly, adapting to dynamic injuries, and designing creative rehabilitation plans on a daily basis to ensure positive outcomes for patients. After characterizing the general profile of our interviewer, we probed further through contextual understanding to identify what constitutes a successful rehabilitation, the limitations of current therapies, and the direction of promising new treatments.

To determine what constitutes a successful rehabilitation, we asked our interviewer to walk us through how they would treat a patient from beginning to end. As we listened to this process, we made note of shared treatment objectives that were common to all patients, regardless of hand injury type. From this line of questioning, we learned that our interviewer characterizes a successful treatment in two ways: 1) one that does not inflict further harm and 2) one that restores function. From this, we identified safety of treatment as the highest priority when administering therapeutics for hand injuries. Additionally, we found that while restoring function is a common goal regardless of injury type, ultimately the treatment varies with the functional needs of each individual based on their distinctive, everyday tasks.

Next, we probed about the limitations of current therapies by noting the inconveniences repeatedly mentioned by our interviewer. From our interviewer's general treatment approach and most commonly administered therapies, we identified incomplete visualization and low customizability to be defining limitations of current hand therapies. Both of these limitations were most prominent when our interviewer discussed the challenges of designing custom hand splints for complex injuries featuring open wounds, acute pain, and even requiring immediate surgery. These additional complexities make visualization of the injury difficult and results in low customizability of therapeutics which ultimately limits the capacity of a treatment plan to successfully address all aspects of the injury in need of rehabilitation.

Finally, we inquired about promising new treatments and if they enhanced treatment outcomes by addressing our identified limitations. As anticipated, our interviewer discussed the rise of high-tech imaging techniques such as 3D scanning to non-invasively replicate patients' site of injury to better inform treatment options. Furthermore, our interviewer addressed customizability by discussing the use of 3D printing to develop custom-fit hand orthotics. We learned that while these technologies that address the limitations of visualization and customization are widespread, they are not often employed due to their high operational costs.

Resultantly, we focused more on a more accessible promising new treatment known as Mirror-Box Therapy that our interviewer mentioned multiple times. This therapy utilizes visualizations of regained function, for example, from executing motor tasks with the uninjured hand, to restores function in the injured hand as well. By nature, this treatment fulfills the customization need as it is individualized to each patients' functional abilities and injury-type and enhances visualization through the mirror-box setup. Additionally, we learned about unexpected, intangible aids in treatment: self-confidence and passion. Our interviewer emphasized often that rehabilitation of the hand require a cooperative partnership between patient and therapist; while it is important that the therapist provide an effective treatment plan, it is equally important for the patient to possess the internal motivation to regain any lost function. Our interviewer found that treatment plans that capitalize on the patients' self-confidence and passion to rehabilitate their injury results in more successful treatment outcomes.

Primary User-Needs
1. Product/treatment avoids causing pain to the patient and can adjust around existing hardware.
2. Product/treatment causes no other injuries to the patient as a side effect.
3. Product/treatment allows patients to return to activities they are passionate about.
4. Product/treatment restores function to the patient's everyday tasks.
5. Product/treatment promotes self-confidence in the patient to use the recovering body part.

Fig. 1: Top five user-needs distilled from our interview.

Based on our interview, we distilled the needs that our product is intended to address to best aid in the therapy of hand injuries. While keeping the themes of safety, visualization, customizability, accessibility, and the patient's internal motivation in mind, we identified five needs statements, as displayed in Figure 1. The product must avoid causing pain or further injuries and adjust around existing hardware while promoting self-confidence and allowing the patient to return to daily tasks and the activities they are passionate about. Upon further exploration of these concepts, we were motivated to study the importance of activating the mind during recovery and the healing power behind triggering patient self-confidence and motivation. We also were curious as to how we could take what we learned in the interview about the existing technology of Mirror Therapy and improve the system past the already powerful mental recovery that takes place during this treatment. We hoped to explore the coupling of visualization with proprioception to produce an optimized form of care.

III. Methods

A. Study Overview

In this proposed single-blind, randomized study, the objective is to restore function in subacute stroke patients experiencing upper extremity paresis through a novel mirror and EMG-EStim (M-EE) device. This device enhances the therapeutic potential of Mirror Therapy with an EMG-EStim system that detects activated muscles in the functional arm during a simple motor task and stimulates corresponding muscles in the affected arm to replicate the motion.

First, eligible patients will be randomly recruited from rehabilitation centers via advertisements. From this pool of interested participants, individuals are screened to rule out contraindications that would compromise their health. After screening, selected participants are assessed for baseline function in both upper extremities and randomly split into two groups: 1) the control group and 2) the experimental group. The control group undergoes conventional Mirror Therapy alone while the experimental group employs the M-EE device. After receiving treatment multiple times a week for three months, the typical minimum duration of post-stroke paresis recovery, subjects are reassessed for post-intervention motor function in upper extremities to draw conclusions about the rehabilitation potential of the M-EE device.

B. Device Description

The M-EE device contains two components: 1) the Mirror Therapy system, and 2) the EMG-EStim system. When utilizing the M-EE device, the subject wears the EMG-EStim system on both arms while completing conventional Mirror Therapy. On the healthy arm, an electromyographic (EMG) sensor, such as the MyoWare Muscle Sensor, is positioned to detect the targeted motor task. On the affected arm, an electrical muscle stimulator, such as the NMES unit from Balego, is placed in an identical location to trigger the targeted motion in the opposite extremity.

Additionally, relays are placed between the electrodes and the EStim unit's body to create an open circuit until triggered. The relays and the EMG sensor are both connected to a microcontroller. When completing targeted motor tasks for therapy, the EMG unit detects a signal from the healthy muscle and sends it to the microcontroller. Then, the microcontroller determines whether this signal meets a specified threshold. If the threshold is satisfied, the microcontroller closes the relays and the EStim unit is powered to stimulate a corresponding motion in the affected arm. Pictured below in Figure 2 is the proposed M-EE device:

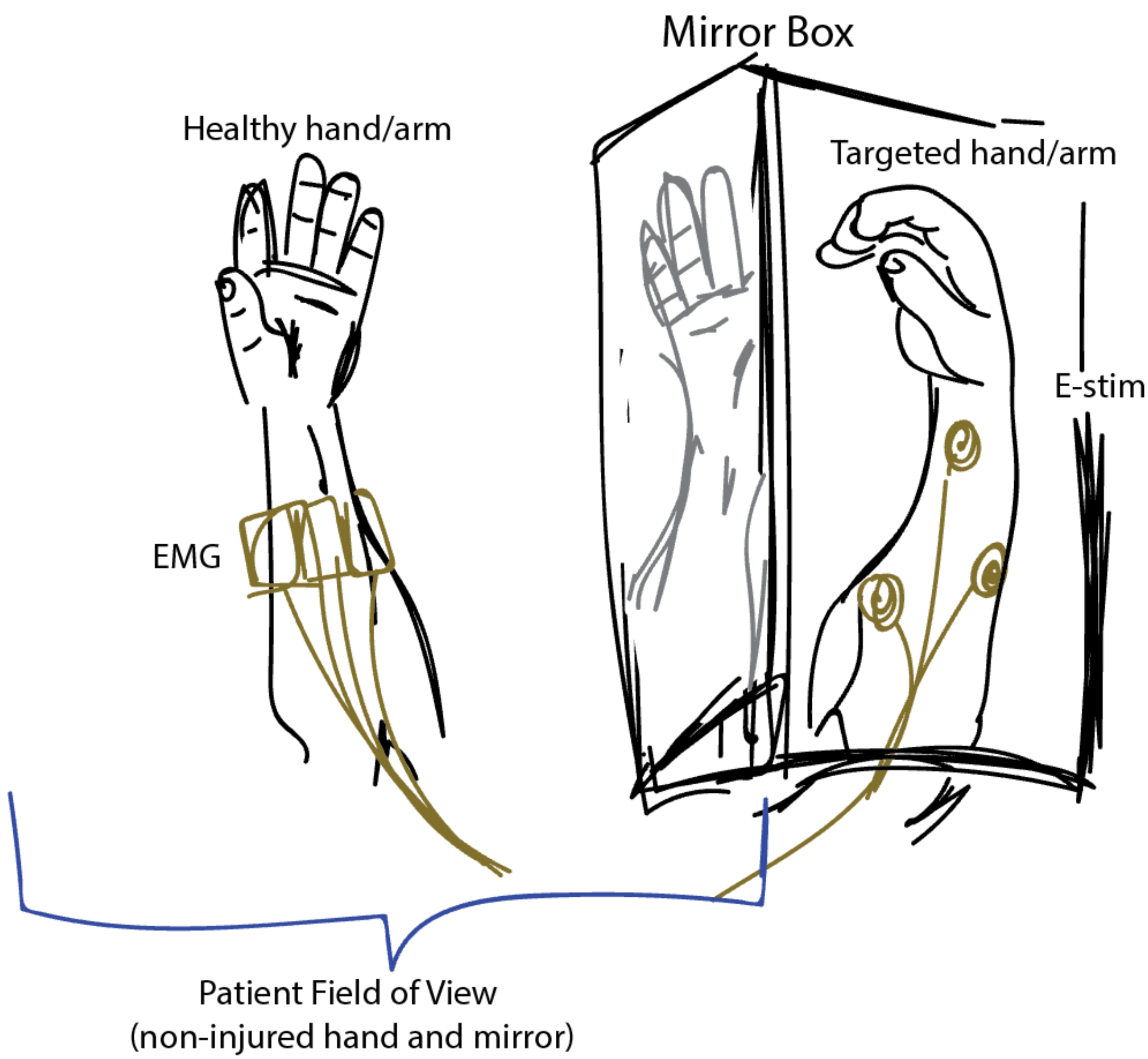

Fig. 2: Sketch of the proposed M-EE device.

The Mirror Therapy system utilizes a mirror that spans from the subject's midsection to the top of their head when placed on the testing table. The mirror is also wide enough to conceal the subject's affected arm when viewed from its reflective side. During therapy, the seated subject is positioned such that the mirror is parallel to their sagittal plane, with the healthy and affected arms on the reflective and non-reflective sides, respectively. Both arms should be in a similar relaxed, outstretched position. Finally, the subject's head is oriented such that the reflection of the healthy arm is at a similar distance as the affected arm would be from their point of view.

C. Testing Procedure

Before experimentation, all subjects are assessed qualitatively by a medical professional to characterize the nature of upper extremity paresis following subacute stroke. Next, baseline motor function is quantified in both the healthy and affected arms via multidimensional motor assessments including the Wolf Motor Function Test, Fugl-Meyer Assessment, and Brunnstrom Recovery Criteria.

Next, treatment is single-blindly administered by a trained professional to both groups. The control group is administered conventional Mirror Therapy; subjects are instructed to slowly and deliberately alternate between gripping their healthy hand into a fist and releasing it while looking at that hand's reflection in the mirror and performing intense visualization to mentally map this reflection onto the affected hand. The experimental group receiving therapy with the M-EE device is instructed to perform an identical motor task while performing visualizations with the provided Mirror Therapy system. Additionally, the experimental group is instructed to imagine the EStim-induced muscle activation in the affected hand as their own musculature activation. Pictured below in Figure 3 is a subject engaged in MT with the proposed M-EE device:

Fig. 3: A demonstration of the M-EE device.

Both groups are administered treatment in thirty-minute intervals, five-times a week as in Schick et al. [11]. To assess the therapeutic potential of the proposed M-EE device within typical stroke recovery timelines, treatment is administered for a minimum of three months with monthly motor function assessments in both arms. Once treatment is complete, upper extremity paresis recovery between the control and experimental groups is compared to draw conclusions about the effectiveness of the M-EE device.

D. Expected Outcomes

In this study, it is expected that upper extremity paresis in subacute stroke patients will recover more quickly and effectively with the M-EE device over three-months than through Mirror Therapy alone.

Further development of this proposed device is expected to include noise-cancelling headphones to further immerse the subject in the Mirror Therapy experience by removing external auditory distractions. Finally, an implementation of electrode pad arrays in the EMG-EStim system would maximize the targeted motor functions that can be utilized to improve therapeutic outcomes during treatment.

IV. Intellectual Merit

The results of this study are of particular interest to current and future professionals in the occupational and hand therapy fields. Through the analysis of Mirror Therapy and its augmentation through EMG-EStim, in addition to the findings of Schick et al. [11]. regarding EMG-EStim and its augmentation through Mirror Therapy, a professional would be able to pinpoint which treatment is optimal for patient rehabilitation.

These results also are of interest to other researchers, as the results found here establish a new baseline for optimum treatment for hand paresis. Future work that builds upon this foundation may include extending this treatment to other conditions such as multiple sclerosis or diabetes; adding further modifications to the treatment platform, like holographic visuals in the reflection or tactile feedback to the targeted hand; or improving the EMG-EStim mirroring by increasing sensor and emitter electrode resolution.

V. Broader Impact

To the thousands of subacute stroke patients with hand paresis, this work may lead to a faster, less painful, and more effective recovery process. Since the combination of Mirror Therapy with EMG-EStim therapy allows for the patient's natural healing process to be the driving factor in rehabilitation, this non-invasive therapy is safe for widespread implementation. Additionally, the relative simplicity of the treatment platform means that a therapy session could be conducted remotely, if such is a necessity or for convenience.

Furthermore, as this field is increasingly explored and its effectiveness on other hand ailments analysed, EMG-EStim-augmented Mirror Therapy and adjacent practices may become a mainstay in physical therapy of the upper extremities, extending its usage outwards towards all patients looking to regain hand dexterity.

References

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APPENDIX A
INVESTIGATIONAL DEVICE DETAILS

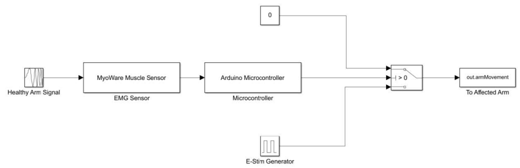

Fig. 4: Block Diagram of EMG-MES System