

THESIS

THE EFFECTS OF PATTERNED SENSORY ENHANCEMENT ON  
HEMIPARETIC UPPER LIMB KINEMATICS

Submitted by

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## ABSTRACT

### THE EFFECTS OF PATTERNED SENSORY ENHANCEMENT ON HEMIPARETIC UPPER LIMB KINEMATICS

Loss of motor capabilities following a stroke can have a significant effect on a stroke survivor's quality of life, and the lack of conclusively effective therapeutic interventions often make it difficult to determine an effective treatment plan. Several empirical studies have found Neurologic Music Therapy (NMT) successful in producing more efficient muscular movements post-stroke (Malcolm, Massie, & Thaut, 2009; Thaut, Schleiffers, & Davis, 1991; Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002; Thaut et al., 2007; Yoo, 2009). The purpose of this pilot study was to assess the effect Patterned Sensory Enhancement (PSE), an NMT technique, had on movement in hemiparetic upper limbs of stroke survivors. Three subjects participated in two counterbalanced experimental trials in which a repetitive reaching movement was evaluated with (1) auditory rhythmic cueing and (2) with combined temporal, force and spatial auditory cueing (PSE). Target contact accuracy and mid-arc variability were statistically analyzed between the three trials (un-cued control, rhythm only, and PSE). Repeated measures ANOVA revealed a decrease in mid-arc variability in the PSE trial, but not at a statistically significant level. No further statistically significant results were discovered in this pilot study, however, more conclusive results may be observed in future studies adhering to the suggested revisions.

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## CHAPTER 1: INTRODUCTION

Cerebrovascular accidents (CVA), more commonly known as a stroke, occur about 795,000 times each year (American Heart Association, 2011). A CVA or stroke takes place when blood supply is cut off from the brain and because the surrounding cells receive no oxygen, the cells die (Davis, Gfeller & Thaut, 2008). The death of brain cells has many negative consequences and people that survive a stroke can have difficulties in speech production, cognitive ability, emotional response regulation, and motor skills, as well as many other deficits. The severity and specific symptoms vary depending on which areas of the brain are damaged and to what extent it is damaged. It is estimated that nearly half of the individuals that suffer a stroke experience moderate to severe disability (Kelly-Hayes, Beiser, Kase, Scaramucci, D'Agostino, & Wolf, 2003). In fact, stroke is the foremost cause of prolonged disability in America (American Heart Association, 2011). Early treatment and rehabilitation is crucial, as the brain is most plastic and able to adapt in the time shortly after the occurrence of the stroke (Ginsberg, 2010; Luft et al., 2004).

One area of need that has seen a great amount of research in rehabilitation post-stroke is motor function. Most everyday tasks require the ability to move and exercise one's body in various ways, such as getting dressed, feeding one's self, and grooming. The ability to accomplish these activities of daily living without assistance leads to an increased independence. Dependence on another individual for regular assistance can contribute to a loss of self-esteem and self-worth. Thus, effective motor ability is often

considered a priority by the patients, their caregivers, and their treatment team when evaluating treatment plans.

Although motor rehabilitation is a significant part of the recovery process for many stroke survivors, sufficient evidence supporting the efficacy of commonly used interventions is lacking (Altenmüller, Marco-Pallares, Münte, & Schneider, 2009). One consistent finding in current research reveals that repetitive isolated movements contribute to neural reorganization and improved motor functioning (Altenmüller et al., 2009). Several studies have found that active music performance further contributes to “rapid plastic adaptation” (Altenmüller et al., 2009, p. 395). This adaptation is seen in the motor cortex and is further distributed to other areas such as the auditory cortex and association areas of the brain (Altenmüller et al., 2009). Furthermore, the neural adaptations occur in both the white and gray matter of the brain ( Schlaug, Altenmüller, & Thaut, 2010). These findings indicate that active music making can stimulate rapid cortical changes that can be utilized in motor rehabilitation (Altenmüller et al., 2009; Schlaug, et al., 2010).

### *Rationale*

Neurologic music therapy (NMT) is an evidenced-based practice that has been shown to optimize and enhance motor movement in people with neurological disorders and injuries (Thaut, 2005). The use of music in rehabilitation is fundamentally based on two principles (Thaut & McIntosh, 2010). First, the areas of the brain that are activated by music are not unique to music (Thaut & McIntosh, 2010). Areas of the brain that are involved in music are also involved in executive function, language processing, memory, attention, auditory perception, and motor control (Thaut & McIntosh, 2010). “Music

efficiently accesses and activates these systems and can drive complex patterns of interaction among them” (Thaut & McIntosh, 2010, p. 3). Music not only shares networks with these cortical tasks, but also utilizes extended networks in the brain (Thaut & McIntosh, 2010). Secondly, active music making physiologically alters the brain, and music can initiate and contribute toward cortical plasticity (Thaut & McIntosh, 2010). These fundamental principals have led to a significant amount of research evaluating music’s therapeutic effect on non-musical functional tasks.

Rhythmic auditory stimulation (RAS) is an NMT technique that has been successful in improving the gait and pre-gait patterns of people with Parkinson’s disease, traumatic brain injuries (TBI), and post-stroke (Hesse, & Werner, 2003; Hurt, Rice, McIntosh, & Thaut, 1998; Pacchetti, Mancini, Aglieri, Fundarò, Martignoni, & Nappi, 2000; Schauer, & Mautriz, 2003; Thaut, McIntosh, Rice, Miller, Rathbun, & Brault, 1996; Thaut et al., 2007).

In a randomized, controlled, single-blinded study evaluating the effectiveness of RAS on motor movements of patients with Parkinson’s disease the researchers ascertained statistically significant results demonstrating a very strong positive effect on several motor functions (Pacchetti et al., 2000). It is worthwhile to note that the participants in the study also mentioned an increase in their ability to complete activities of daily living (ADL’s) without assistance and claimed to have an overall increased feeling of happiness (Pacchetti et al., 2000). The rhythmic auditory stimulation studies provide evidence of the efficacy of music therapy on movement in the treatment of neurological disorders.

The neurological and physiological theory for the efficacy of NMT in neurological rehabilitation is that not only does sound excite the central nervous system, but in fact, “rhythmically structured sound patterns...entrain the timing of muscle activation patterns” (Thaut et al., 1999 p.101). The nervous system responds to external stimuli and shares the sensory information from the stimuli with the motor system. This sensory information acts as an optimizer in motor movement. A simple example of this process is that of a person walking down a street. As he is walking he uses visual sensory input to navigate around obstacles. If there is a tree in his way, his brain receives the visual sensory input, which is then shared with the motor networks. Upon processing the sensory input and sharing it with the motor system, the motor networks adapt the action and the person walks around the tree to prevent injury. Auditory cues create even faster physical responses than visual or tactile cues (Thaut et al., 1999). Therefore using an auditory stimulus can elicit an even more effective and quick response. This phenomenon is utilized in synchronization or entrainment of an auditory stimulus with motor movement. Studies have found that entrainment of motor movements occurs on a subcortical level to an auditory stimulus (Thaut et al., 1996; Thaut et al., 1999; Thaut, Stephan, Wunderlich, Tellmann, McIntosh, Hömberg, 2009). Motor entrainment to an auditory stimulus is seen particularly in intrinsically rhythmic central patterned generators (CPGs).

Central pattern generators (CPGs) are neuronal circuits carrying specific timing information and when activated can produce rhythmic motor patterns such as walking and breathing in the absence of sensory or descending inputs (Marder & Bucher, 2001).

CPGs are mediated subcortically and can be influenced cortically to create “meaningful movement patterns” (Marder & Bucher, 2001, p. R986). Because walking is a CPG, it can entrain to and be regulated by an auditory stimulus. “The presence of rhythmic cues adds stability in motor control immediately” (Thaut et al., 1999, p. 102). Thus, rhythmic auditory stimulation uses a steady, rhythmic stimulus to entrain and regulate gait and pre-ambulatory movements.

Rhythm has been shown to be effective in regulating rhythmically intrinsic movements such as walking. The question then arises; can rhythm increase the efficiency of voluntary, non-rhythmic movements, such as a reaching task in an upper limb?

Several studies have evaluated the efficacy of rhythm-driven NMT techniques in producing more efficient muscular movements in the upper extremities in patients post-stroke (Altenmüller et al., 2009; Malcolm et al., 2009; Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002; Yoo, 2009). Thaut et al. (2002) observed an “immediate reduction in variability of arm kinematics during rhythmic entrainment within the first two or three repetitions of each trial” (p.1073). Another study found statistically significant improvements in wrist and hand movements following Therapeutic Instrumental Music Performance (TIMP) (Yoo, 2009). Malcolm et al. (2009) reported a statistically significant increase in shoulder flexion and decrease in compensatory movement of the trunk following a rhythmic NMT intervention (p.69). Thus, rhythm has a regulating effect on both intrinsically rhythmic and non-rhythmic movements.

One way to further optimize the building of the neural networks and the efficiency of a task is to add supplementary types of sensory input. A more detailed and comprehensive stimulus may be given to the brain by creating an auditory, isomorphic

representation of the movement in regards to space, time, and force. This creates a map for the brain to plan and coordinate the movement enhancing the efficiency and fluidity of the movement. The specific musical elements and patterns provide supplementary feedback to the brain regarding the position of the limb in space and time, and thus contribute to enhanced motor coordination (Thaut, 2005, p. 151). “Patterned Sensory Enhancement (PSE) is an (NMT) technique which uses the rhythmic, melodic, harmonic and dynamic-acoustical elements of music to provide temporal, spatial, and force cues for movements which reflect functional exercises...” (Thaut, 2005). In PSE, the music therapist studies the kinematic motion of the movement and then uses the core elements of music to create a specific auditory representation of the music (Davis et al., 2008). As Thaut (2005) suggested, the auditory representation may help improve proprioceptive and visual feedback when planning and executing the movement.

### *Statement of the Problem*

The purpose of this study was to assess the effect Patterned Sensory Enhancement (PSE) had on functional movement in hemiparetic upper limbs of patients who have had a stroke.

### *Hypothesis*

Null Hypothesis: There will be no statistically significant difference in motor variability between the Patterned Sensory Enhancement (PSE) treatment, “rhythm only” treatment, and the control trial ( $p < .05$ ).

### *Delimitations, Limitations and Assumptions*

This study was delimited to non-musicians who had experienced a stroke no less than six months from the time of the trials. The participants were required to have at least

minimal motor function in the paretic limb to complete the task. Also, the subjects had no additional health conditions that could potentially harm them during the experiment, as well as no other neurological disorders.

It was assumed that the participants would continue their plan of care as usual.

## CHAPTER 2: LITERATURE REVIEW

### *Introduction to Stroke*

Stroke remains the principal cause of long-term disability in America, with an estimated 795,000 strokes occurring annually (American Heart Association, 2011).

Stroke is the third highest cause of death in the United States, responsible for an estimated 140,000 lives lost every year (American Heart Association, 2011). Advances in medicine in the past fifteen years have helped to decrease the number of stroke fatalities and the increased survival rate accounts for an estimated 6,400,000 stroke survivors alive today (American Heart Association, 2011). Damage to the nervous tissue leaves nearly half of the stroke survivors facing moderate to severe disability, the severity depending on the location and extent of damage to the nervous tissue (Kelly-Hayes et al., 2003; Nolte, 2009).

Damage to the brain occurs when the nervous tissue is deprived of oxygen (Nolte, 2009). This can occur due to a blockage of blood flow (ischemic stroke) or a hemorrhage (hemorrhagic stroke) (Nolte, 2009). Ischemic stroke is the most common type of stroke, responsible for an estimated 87% of all strokes (American Heart Association, 2011).

The blockage in an ischemic stroke is due to either a blood clot inside a vessel going to the brain (thrombus), or a fragment of foreign substance that has formed elsewhere and circulated in the bloodstream (embolus) (Nolte, 2009). Thrombotic and embolic strokes are largely associated with atherosclerosis, an accumulation of plaques in the arteries (Nolte, 2009). The duration of an ischemic stroke can vary from a few minutes to a few hours and can be treated using a tissue plasminogen activator (tPA)



within the first 4.5 hours of the stroke onset (American Heart Association, 2011). The TPA is an FDA- approved pharmaceutical that breaks down the blood clot and can prevent fatality and greatly reduce long term consequences of a stroke (American Heart Association, 2011).

Closely related to the ischemic stroke is a transient ischemic attack (TIA) (Nolte, 2009). As the name would imply, the blockage in a TIA is briefer in duration than an ischemic stroke and the deficits from a TIA are usually less severe (Nolte, 2009). Many people that experience a TIA recover completely, however, TIA survivors are at an increased risk of stroke for five years following the TIA (Ginsberg, 2010; Nolte, 2009).

A hemorrhagic stroke occurs when a blood vessel ruptures and causes bleeding in the brain (Shannon, 2003). The crossing of the blood past the blood-brain barrier causes damage to the nervous tissue and in some cases may even displace brain issue (Shannon, 2003). A subarachnoid hemorrhage is caused by the rupture of a cerebral aneurism and can have particularly devastating effects (Nolte, 2009).

All types of stroke have a potential to cause significant damage in the brain and the recovery process varies from person to person (Davis et al., 2008). During the acute phase of recovery, patients often see spontaneous recovery due to natural neural reorganization (Carr & Shepherd, 2003; Davis et al., 2008). Spontaneous recovery varies from case to case and as such, many stroke survivors are left with impairments that significantly impact their quality of life. Deficits are seen in cognition, emotional response regulation, memory, speech production and comprehension, sensory impairments, and motor ability (Davis et al., 2008). To regain as much of their previously

learned abilities as possible, many stroke survivors undergo some form of rehabilitation (Baker & Roth, 2004).

### *Stroke Rehabilitation*

Rehabilitation is important to many stroke survivors to increase their quality of life and lessen the physical and financial burdens on themselves, family members and society in general (Geyer & Gomez, 2009). The goal of rehabilitation is to restore the client to their previous level of functioning or to the highest level of competence possible within the limitations of their given disability (Baker & Roth, 2004; Ginsberg, 2010). Varying levels and types of disabilities respond differently to various types of therapy (McCombe Waller & Whitall 2008). It is generally recommended that a multidisciplinary team be employed in order to accommodate for a variety of needs in rehabilitation (Carr & Shepherd, 2003; Ginsberg, 2010).

One of the core elements of many stroke survivors' rehabilitative care is motor rehabilitation (Geyer & Gomez, 2009). Not only does mobility and functional motor ability contribute to general quality of life, but it also prevents further damage to the body. Immobility and lack of motor function can lead to bed sores, deep vein thrombosis, pneumonia, skin breakdown, gastroesophageal regurgitation and muscle atrophy (Geyer & Gomez, 2009). As such, functional motor ability is a high priority when considering a rehabilitative treatment plan and is recommended to commence as soon as possible (Geyer & Gomez, 2009).

As important as motor rehabilitation is for stroke survivors, it is a significant challenge for healthcare providers due to an overwhelming lack of evidenced-based treatments (Altenmüller et al., 2009; Carr & Shepherd, 2003). The shortage of reliable

research and quality evidence impairs the healthcare providers' ability to make well grounded and evidence-based decisions. This deficiency has led researchers to look beyond conventional therapies to novel treatments (Altenmüller et al., 2009; Liepert, 2010). Treatments currently used include pharmaceutical drugs, strength training, electrical stimulation, and constraint-induced therapies (Hesse & Werner, 2003). Many of these interventions are under scrutiny and have inconclusive results due to small sample size, insufficient and conflicting replication studies, and a lack of internal validity (Altenmüller et al., 2009). One such debated intervention is constraint-induced movement therapy (Liepert, 2010).

Constraint-induced movement therapy (CIMT) is a somewhat controversial intervention that has yielded inconclusive results (Liepert, 2010). In this form of therapy, the non-affected limb is restrained and immobilized to stimulate more functional movement of the affected limb. The rationale of this therapy is that consistent non-use during the acute stage of recovery can create negative reinforcement and learned non-use (Hesse & Werner, 2003, p. 1101). It appears that a portion of the unreliable results evaluating this intervention likely arose from insufficient internal validity. For instance, one CIMT study compared the results of two groups of participants, one group received CIMT and the other group, the control group, received a different form of therapy (Liepert, 2010). The alternative form of therapy was a less intense form of training that undermined the causal relationship between the intervention and the results (Liepert, 2010). Conversely so, several studies have found that CIMT is an effective intervention for upper limb motor rehabilitation (Liepert, 2010). Many of the favoring studies supporting the efficacy of CIMT have been evaluating chronic stroke, having found that

CIMT appears to be effective in improving arm, but not hand function (Liepert, 2010). In regards to the treatment phase, CIMT may even be harmful in the acute phase of stroke rehabilitation. In a rare acute study, patients actually had significantly poorer results than the control groups when the CIMT was carried out more intensely. Thus, CIMT may be effective in improving upper limb movement in chronic stroke cases with special attention paid to intensity of training, but more evidence is needed to draw definitive conclusions.

As with many therapies, constraint-induced movement therapy may be more effective when combined with alternative interventions. One study combined CIMT with botulinum toxin type A (Btx) injections and demonstrated statistically significant results. The Btx/ CIMT group demonstrated decreased spasticity and had “more real-world arm function measured by the Motor Activity Log than the control group” (control group received Btx and a similar long-term therapy) (Liepert, 2010, p. 679). This study was important as well because of the implications that Btx not only decreased spasticity, but also improved motor functions.

It has been conclusively shown that Btx reduces spasticity in upper limbs after stroke (Olvey, Armstrong, & Grizzle, 2010). Less information has surfaced in regard to Btx being used in improving motor capabilities (Liepert, 2010). There has been a limited amount of studies conducted evaluating the efficacy of Btx as an adjunct therapy in motor rehabilitation (Liepert, 2010). The few studies that have been done for that purpose have yielded inconclusive and conflicting results, some studies finding improvement, others reporting no changes (Liepert, 2010). Slightly more studies involving Btx have been conducted with children that have been primarily diagnosed with spastic cerebral palsy

(Liepert, 2010). One study demonstrated improvement in motor capabilities, however, the effects seem to be short-term (Liepert, 2010). Another study increased the length of time the injections were given to the children and reported significant results (Liepert, 2010). However, improvements were reported by the parents of the children with very little, if any, quantitative evidence (Liepert, 2010). This lack of quantitative evidence and insufficiently reliable testing measures decreased the validity and reliability of the results. Amidst the conflicting evidence, it is stressed that Btx should not be implemented singularly, but rather if Btx is used, it should accompany other forms of rehabilitative therapy such as occupational therapy (Liepert, 2010). As such, Btx has shown to decrease spasticity in the limbs of stroke survivors, but more evidence is needed to demonstrate it's conclusive effect in improving motor functioning.

Another novel intervention for rehabilitation of stroke survivors is passive sensory training. Passive sensory training involves a cutaneous electrical stimulation that the patients use "to detect, localize and discriminate somatosensory signals" (Liepert, 2010, p. 680). Participants not only saw improvements in sensory deficiencies but also experienced improvement in motor functioning (Schabrun & Hillier, 2009). Many questions still need to be answered in regards to this novel intervention involving the testing of the best level of intensity and duration of treatment, and the longevity of it's effect (Liepert, 2010, p. 680).

Physical therapy, in general, has greatly assisted people that have lost motor skills due to trauma, injury and illness. The field of physical therapy is an evidence-based discipline with many empirically supported techniques. Many stroke survivors undergo some form of physical therapy, with many of the techniques showing consistent and

positive effects. Other techniques used in physical therapy have yielded inconclusive results and require further research to determine efficacy.

Repetitive training of isolated movements has shown to be effective in improving motor functioning post-stroke in several strong studies with sufficiently large sample sizes (Hesse, & Werner, 2003). This success may be due to the fact that repetition aids in building stronger neural networks. Strong neural networks produce more efficient processing and completion of tasks. Even though repetitive training of isolated movements demonstrates significant results, a few important factors should be noted. First, the positive effects may be limited to the short term or acute cases. Hesse & Werner (2003) observed that statistically significant results were limited to the 6-month follow-up in one of the studies analyzed in his review. Secondly, repetitive training of isolated movements is not ideal for all stroke survivors, particularly patients that have little endurance and/ or pain when performing repetitive movements.

Another closely related intervention to repetitive training of isolated movements is strength training. Resistance training has consistently demonstrated effectiveness in increasing muscle strength (Liepert, 2010). This is relevant to stroke survivors because reduced strength is a common symptom after a stroke (Liepert, 2010). Increased muscle strength via resistance training can occur at any age with contributing changes from both the muscle (hypertrophy) and the nervous system (Gabriel, Kamen, & Frost, 2006; Tracy, Byrnes, & Enoka, 2004; Tracy & Enoka, 2006). In a meta-analysis, Harris & Eng (2010) reported that strength training post-stroke increased grip strength and upper-limb function. However, significant changes were not seen when measuring activities of daily living. Even so, strength training still holds significant promise in improving motor

functioning for stroke survivors, particularly because no adverse affects were reported (Harris & Eng, 2010).

Other techniques utilized in physical therapy breed polarized and controversial views supported by conflicting evidence. One such technique is Bilateral Arm Training with Rhythmic Auditory Cueing (BATRAC) (Liepert, 2010). Many studies have been conducted seeking to evaluate the efficacy of BATRAC in improving upper limb motor functionality (Liepert, 2010; Luft et al., 2004). However results have been quite varied making it difficult to conclusively determine its usefulness. The question many researchers have posed is; “Is bilateral arm training superior to unilateral arm training?” (Van Delden et al., 2009). Some medical professionals maintain that bilateral is superior, where as in others insist that it is not superior (Van Delden et al., 2009). Multiple studies can be found that support either sides of the argument (Van Delden et al., 2009; Luft, et al., 2004). The rationale behind training both arms at the same time is that there are connections between the two limbs in the nervous system (Richards, Senesac, Davis, Woodbury, & Nadeau, 2008). That in fact the ipsilateral movement is mirrored contralaterally and the connection between the two sides can be used to improve movement in the affected side (Richards et al., 2008). When exclusively comparing unilateral training against bilateral training the majority of the studies have found little statistically significant difference between the two methods (Liepert, 2010). However, McCombe Waller & Whitall (2008) suggest that the effort be made to *combine* unilateral and bilateral training to produce the most significant overall functional improvement in the upper limbs. This concept of combining unilateral and bilateral training is functionally relevant and logical in that many activities of daily living require a

combination of unilateral and bilateral movement. McCombe, Waller & Whittall (2008) also stated that differing levels of training would need to be considered for different levels of disability and further replication studies are still needed. Regardless if training is performed with one arm or with both arms, the repetitive nature of the training is likely the main source of improvement, creating more efficient neural networks.

Another category of novel interventions for motor rehabilitation is extrinsic feedback. Extrinsic feedback is a large category of interventions that utilize sensory information to provide feedback either during or after a task (Subramanian, Massie, Malcolm, & Levin, 2010). This feedback is provided by an external source, can be verbal or nonverbal, and can be used in conjunction with intrinsic feedback (proprioceptive, tactile, etc.) or used alone (Subramanian et al., 2010). In a meta-analysis, Subramanian, et al., (2010) consistently demonstrated that extrinsic feedback successfully contributed to motor learning. Extrinsic feedback demonstrated significant promise in aiding motor rehabilitation, but more research is needed to draw definitive conclusions.

### *Neurologic Music Therapy*

Neurologic music therapy is a novel intervention that utilizes sensory feedback and extended cortical networks in a noninvasive way to aid in rehabilitation (Thaut & McIntosh, 2010). Music is processed in the same areas of the brain as memory, language, attention, and motor mapping and is further processed in extended, widely distributed networks bilaterally. Beat perception activates the following areas of the brain bilaterally: supplementary motor area, primary motor cortex, insula, superior temporal gyrus, cerebellum and putamen (Grahn & Rowe, 2009). The perception of a beat also activates Broca's area and Wernicke's area, two cortical areas that are used in speech production



and comprehension (Grahn & Rowe, 2009). The activation of Broca's area is important because of Broca's role in speech production as a regulator of sequencing and adherence to structural rules that are common in not only speech, but are also present in music and movement (Thaut, 2005; Thaut & McIntosh, 2010). An increased connectivity between the putamen and the auditory cortex, supplementary motor area, and premotor cortex were also seen with the presence of a consistent beat (Grahn & Rowe, 2009). This connectivity is implicated in the enhanced motor coordination that is seen when movement is combined with rhythm. The extended networks and wide distribution of music processing provide pathways in which music can be used to drive communication between functional areas of the brain (Thaut & McIntosh, 2010). Engaging in active music making causes new connections to form and drive neural adaptations and plasticity (Thaut & McIntosh, 2010).

Cortical plasticity is a fundamental element of rehabilitation after an injury as the brain forms new connections and networks needed to relearn a previously acquired skill or learn a compensatory skill (Baker & Roth, 2004; Thaut & McIntosh, 2010). A recent study performed by Lahav, Saltzman, & Schlaug (2007) demonstrated rapid cortical adaptations that occur when actively engaging in music, which can be used in functional rehabilitation. Additionally, "Making music... leads to a strong coupling of perception and action mediated by sensory, motor, and multimodal brain regions" (Schlaug et al., 2010, p. 249). Lahav et al. (2007) reported significant results related to action-related sounds and the cortical activations present when listening to the action-related sound. In this study, nonmusicians were taught a simple piece of music on the piano over the course of five days (Lahav et al. 2007). At the end of the five days, an fMRI was used to

evaluate cortical activations when listening to the familiar piece of music learned by the nonmusicians, unfamiliar music, and the familiar music with the notes out of order (Lahav et al. 2007). The participants were instructed to not move during the fMRI evaluation, they simply listened to the music (Lahav et al. 2007). When listening to the unfamiliar music the primary cortex was activated as would be expected (Lahav et al. 2007). When the nonmusicians listened to the familiar piece of music the following areas were bilaterally activated: “frontoparietal motor-related network (including Broca’s area, the premotor region, the intraparietal sulcus, and the inferior parietal region)” (Lahav et al. 2007, p.308). These activations show that the sensory (auditory) information activated motor networks without any actual physical movement. This theory of a “mirror-neuron system” is implicated in the learning of motor movement and this study suggests that music can function as a mediator in the neural processes (LaGasse, 2010b; Lahav et al. 2007).

The temporal element of music acts as a timing signal in motor tasks (Thaut & McIntosh, 2010). Entrainment to an auditory rhythmic stimulus provides structured temporal organization that helps map a motor movement (LaGasse, 2010b; Thaut, 2005). This mechanism is thought to be primarily carried out via connections between the auditory system and the motor system by way of the reticulospinal tract, a motor tract identified as the main back-up motor tract when the primary motor tract, the lateral corticospinal tract, is damaged (Fails, 2011; Thaut 2005). Auditory information is shared with cortical motor areas and is also shared with the cerebellum, which is thought to enhance synchronization and further coordinate movement (Fails, 2011; Thaut, 2005; Thaut, Stephan, Wunderlich, Tellmann, McIntosh, & Hömberg, 2009). Connections are

also seen between the auditory system and the basal ganglia, structures that are also involved in the initiation, timing, and sequencing of movement (Fails, 2011; Thaut, 2005). Entrainment of an auditory stimulus to a motor movement provided by the cortical and subcortical connections can help facilitate improved motor functioning (Thaut, 2005).

The clinical use of music to facilitate functional motor rehabilitation after an acquired brain injury is efficacious because of the following empirical neurological findings: music is processed in widely-distributed shared and extended networks, rapid cortical adaptations occur when actively engaged in music, entraining to a rhythmic stimulus organizes and maps motor movement, and music can be used as a mediator in perception and activation neural processes (Grahn & Rowe, 2009; Lahav et al. 2007; Schlaug et al., 2010; Thaut, 2005; Thaut & McIntosh, 2010).

Clinical protocols, applications and techniques have been developed based on the neurological findings regarding the therapeutic effects of music (Thaut, 2005). Rhythmic Auditory Stimulation (RAS), Therapeutic Instrumental Music Performance (TIMP) and Patterned Sensory Enhancement (PSE) are NMT techniques that use the therapeutic elements of music, particularly rhythm, to facilitate improved motor functioning.

#### *Rhythmic Auditory Stimulation*

Rhythmic Auditory Stimulation (RAS) utilizes auditory rhythmic cueing to improve gait and gait parameters in patients that have experienced neurological disease or injury (Thaut 2005). The cueing is typically carried out with a metronome, but an autoharp can be used to create more specific cues for specific gait deficits. RAS has been found to be effective in improving gait of individuals with Parkinson's Disease, traumatic

brain injuries (TBI), and post-stroke (Hesse, & Werner, 2003; Hurt et al., 1998; Pacchetti et al., 2000; Schauer, & Mautriz, 2003; Thaut et al. 1996). The efficaciousness of RAS as an effective gait intervention has become more and more established and RAS is now being used in other rehabilitative disciplines (Thaut, 2005).

The success of RAS in improving gait and gait parameters has led to several studies conducted evaluating the effects rhythm may have on improving motor functioning in upper limbs. Malcolm et al. (2009) evaluated five stroke survivors that participated in a 2-week intervention of RAS applied to the upper limbs. The post-test showed a “decrease in compensatory trunk movement, an increase in shoulder flexion, and a slight increase in elbow extension” (Malcolm et al. 2009, p. 69). Thaut et al. (1991) evaluated the influence of rhythmic cueing on EMG patterns in the muscles of upper limbs. They perceived that rhythmic cueing increased muscle activity and helped the participants to effectually anticipate and plan the movements.

The successful application of rhythm as a therapeutic intervention in motor rehabilitation led to the development of new sensorimotor techniques to be used for volitional movements. These techniques are Therapeutic Instrumental Music Performance (TIMP) and Patterned Sensory Enhancement (PSE).

#### *Therapeutic Instrumental Music Performance*

Therapeutic Instrumental Music Performance (TIMP) is an evidenced- based technique that utilizes rhythm and the playing of instruments to facilitate improved motor functioning. In TIMP, repetitive movements are cued using an auditory rhythmic stimulus as the client plays an instrument on the beat. The instruments are selected and strategically placed to emphasize “range of motion, endurance, strength, limb

coordination, functional hand movements, finger dexterity, and limb coordination” (Thaut, 2005, p. 139). During TIMP, a music therapist provides individualized auditory cueing and instrumental playing that is specific to each client’s disability and motor needs. As with RAS, a consistent rhythmic stimulus aids in the planning, mapping and coordination of the movement. Additionally, the instrumental playing mediates the perception-action neural processes involved in motor learning. The instruments in TIMP create additional auditory and tactile feedback, as well as visual targeting when the client makes contact with the instrument. Additionally, TIMP is nonspecific in regards to laterality.

Yoo (2009) conducted a study evaluating the effectiveness of TIMP in improving motor function in hemiparetic upper limbs (post-stroke). Three stroke survivors participated in six 35-minute sessions using TIMP on drum set (Yoo, 2009). The arm movements were assessed both pre and post test utilizing the Fugl-Meyer Test, the Barthel Index, and the Modified Ashworth Scale (MIDI data was also collected) (Yoo, 2009). Significant improvements in wrist and hand functionality (Fugl-Meyer Test) as well as an overall increase in velocity (MIDI) were seen in the results of this study (Yoo, 2009).

Another study was conducted in which Altenmüller et al. (2009) evaluated 32 stroke patients over a 3-week period in which the participants received 15 sessions of guided functional instrumental performance (Altenmüller et al., 2009). A control group of 30 patients received standard rehabilitative care. The treatment group saw improvements in gross motor skills in regards to precision, speed, and smoothness of the movements (Altenmüller et al., 2009, p. 395). Additionally electrophysiological

adaptations were seen that suggest better cortical connectivity (Altenmüller et al., 2009, p. 395).

These studies evaluating functional goal-oriented instrumental playing found statistically significant results showing improvements in functionality of hemiparetic limbs. The neurological principles that underlie TIMP suggest that more replication studies will find TIMP to be an effective intervention.

### *Patterned Sensory Enhancement*

Because several of the most effective elements of common interventions are combined in Patterned Sensory Enhancement (PSE), PSE is likely to have similarly efficacious results. PSE utilizes repetitive isolated movements that are related to stronger and more effective neural networks as well as rhythmic entrainment that coordinates and sequences the movement. PSE provides supplementary auditory cueing by providing not only a rhythmic cue, but also a spatial and a force cue. This supplemental sensory cueing provides additional information that the brain can use to plan, coordinate, and execute a movement. Pitch patterns relate information to the brain about the spatial changes of the movement (Thaut, 2005). The dynamic and harmonic cues simulate the force of the movement and muscle activations (Thaut, 2005, p. 139). Because the brain is also processing melodic and harmonic elements, PSE activates more areas of the brain than interventions that primarily use rhythm (LaGasse, 2010; Thaut 2005). The use of further extended networks may contribute to increased cortical plasticity. As with TIMP, music is also used in PSE to mediate perception-action neural processes that contribute to motor learning. PSE can be used in many diagnoses, for many different functioning levels, and

the cues provided are specific to the movement and are individualized for the patient's needs.

A study performed in a long-term care facility evaluated exercise performance with PSE and also with big-band background music (O'Konski, Bane, Hettinga, & Krull, 2010). The subjects participated in 3 twenty-minute sessions of exercise with PSE, and 3 twenty-minute sessions of exercise with big band background music (total trials= 6) (O'Konski et al., 2010). There were 19 seated-exercises performed by the participants in each session/ trial (O'Konski et al., 2010). The music used for the PSE trial was prerecorded using a keyboard. Notably, the use of prerecorded music eliminated the opportunity for the facilitator to create an adaptable cue, specific to the client's ability and speed.

The participants were videotaped and the tapes analyzed by two observers (O'Konski et al., 2010). The observers evaluated the number of repetitions performed in both trials, the synchrony with the facilitator, range of motion, and form (O'Konski et al., 2010). The measurements used to evaluate the interventions were not truly objective or quantitative because they were based on the observer's relative opinion. For example, when evaluating the videotapes, the observers attached post-it notes to the screen of the monitor to mark the participant's range of motion (O'Konski et al., 2010). Additionally, "Form was coded on a 0 to 2 scale, with 0 indicating poor form; 1 indicating deterioration of form over time or averaging quality form throughout the exercise; and 2 indicating good form" (O'Konski et al., 2010, p. 128-129). This study had several flaws in structure and theory that make it insufficient evidence for or against PSE. The authors were unable to find any significant differences between the trials aside from a slight increase in

repetitions in the PSE trial (O'Konski et al., 2010). The participants reported more enjoyment in the big band music trial and consciously perceived the big-band trial to be a better work out (O'Konski et al., 2010). It seems likely that the inherent problems with the study contributed to the lack of quality results. Further PSE studies are needed to evaluate the efficacy of PSE and it's effect on motor functioning.

Many techniques are currently being researched to increase the evidenced-based rehabilitative options available to stroke survivors for motor therapy. PSE holds significant promise as an effective, non-invasive intervention in improving motor functioning. However, increased amounts of quality evidence are needed to evaluate it's efficacy and support it's use with patients post-stroke.



## CHAPTER 3: METHODOLOGY

### *Human Subjects Approval*

This pilot study was conducted after receiving the approval of the Human Subjects Committee at Colorado State University (Appendix A). All participants read and sign the approved consent form (Appendix B) prior to participating in the study.

### *Participants*

Three participants who had a stroke were recruited from an outpatient rehabilitation clinic and a local hospital to participate in this pilot study. To ensure that this treatment would work regardless of musical experience or ability, only non-musicians were used in this study. A non-musician was defined as a person that is not currently employed as a professional musician or music teacher. The participants were required to have at least minimal motor function in the paretic arm and the capability of following simple instructions. The stroke onset must have occurred no less than six months from the time of the trials to control for natural neural reorganization. The subjects did not have any further potentially harmful health conditions or other neurological disorders. The participants continued with their plan of care as usual.

Table 1

### *Subject Characteristics*

| Subject | Gender | Age          | Stroke Side | Stroke Onset |
|---------|--------|--------------|-------------|--------------|
| 1       | Male   | 55 years old | L CVA       | 3 years ago  |
| 2       | Male   | 84 years old | R CVA       | 14 years ago |
| 3       | Male   | 80 years old | R CVA       | 6 years ago  |

### *Procedure*

The participants were seated in a chair in front of a graphed (centimeters) table with two copper touch-sensitive targets on the surface. The sensors were placed where the middle finger naturally struck the near target during elbow flexion and the far target during maximum extension (on a horizontal surface). The markers were adjusted accordingly to accommodate different arm lengths of the participants. Each participant was instructed to alternatively tap the near and far targets as evenly as possible, at his or her own pace for 30-40 seconds, with a minimum of five near target contacts and five distal target contacts. Trial times (30-40 seconds) were similar to those of other related and similar studies (Malcolm et al., 2009; Thaut et al., 2002). The participants performed the same task with auditory rhythmic cueing (30-40 seconds) and with PSE (30-40 seconds). The tapped frequency selected by the subject was concurrently entered (tapped simultaneously) into a metronome application on an Ipad 2 (Model number= MC97911). The metronome application for Ipad, Tap Metronome, provided the rhythmic auditory stimulus by calculating the tempo (beats per minute) from the self-paced trial and audibly reproducing the same tempo for the rhythmic cued trial (Soper, 2010). PSE was facilitated on an autoharp, adding a spatial and force cue, to the temporal cue. Sony earbuds were plugged into the Ipad 2 for the facilitator to match the tempo established in the self-paced trial. Only the facilitator heard the “Tap Metronome” and the participants synchronized their movement to the auditory stimulus provided by the autoharp.

A counterbalanced design of the PSE trials and rhythmic trials was used to control for order effects. The participants were randomly assigned into 2 groups. Group A performed the trials in the following order; self-paced trial, rhythmic cued trial, PSE cued

trial. Group B performed the trials in the following order; self-paced trial, PSE cued trial, rhythmic cued trial. The participants received a 2-minute rest in between each of the three trials.

#### *Music Stimulus (PSE)*

PSE was facilitated on an autoharp using either a 2/4 or a 6/8 meter. The person facilitating PSE used her clinical judgment in selecting the meter, considering factors such as the speed of the subject-selected tempo and the manner in which the upper limb moved. For example, if the subject's self-selected tempo was below 50 beats per minute, the facilitator used the 6/8 meter and subdivided the beat. The spatial cue was produced with a strum pattern that ascended the upper half of the autoharp (pitch rose) during elbow extension, and descended the lower half of the autoharp (pitch lowered) during flexion. Applying more force to the strings during the ascending/ flexion portion of the movement and less force during the descending portion of the movement created the force cue. The rhythmic cue was provided by the steady and accented rhythmic pulses of alternating ascending and descending cues on the autoharp.

#### *Data Recording*

The participants' movements were recorded using three Panasonic color CCTV digital cameras (model wv-c1350). A one-centimeter reflective marker attached to a fitted copper circuit connector was placed on the most distal tip of the middle finger of the subject's paretic limb. The connection between the copper circuit connector (on the finger) and the copper target created an analog trigger at the beginning of each target contact. The contact produced a visual marker in the form of a flash on the upper left portion of the screen and was utilized to align the three camera views temporally after the

three videos were downloaded. The synchronization flash was used to identify a synchronization frame in order to crop and digitize the data. Once the synchronization frames were identified for all three camera views, the videos were cropped and triangulated into the three dimensional (3-D) spatial model.

The placement of the reflective marker on the middle finger was then outlined frame by frame, in each camera view, for the duration of the trial. This process was repeated with each subject for each trial. The 3-D coordinates of the middle finger, the points of contact on the copper disks, and the midpoints of the trajectory path were extracted and digitized using Vicon Motus 9.0 software (Vicon Motion Systems Inc., 2006). The Butterworth filtering method was employed to digitally filter the data at 6 Herz. Vicon Motus produced a data file with the 3-D coordinates of the finger maker and trajectory cues for the trial that was then imported into Matlab software (MathWorks, Inc., 2008). Custom written Matlab computer software calculated statistics for target contact accuracy (TCA) and mid-arc variability (MAV). TCA and MAV were used to evaluate kinematic variability and accuracy and the effectiveness of the interventions.

### *Statistical Analysis*

#### ***Target Contact Accuracy***

The Matlab software calculated each point of contact (distal and proximal), the mean point of contact, the mean distances from the mean point of contact, and the standard deviations from the mean. Repeated measures analysis of variance (ANOVA) was used to compare the mean distances of the trials to test for significant treatment effect. Pairwise differences were used to evaluate interaction and order effects if main effects were found statistically significant.

### *Mid-Arc Variability*

The Matlab software computed the points in which the middle finger was in vertical mid-arc ( $yz$  plane) between the two copper targets. The Matlab software calculated the mean midpoint of the trajectory path, the mean distances from the mean midpoint, and the standard deviations from the mean. These calculations were made for both extension and flexion and demonstrated the variability of the movement in the vertical mid-plane. Repeated measures analysis of variance (ANOVA) was used to compare the mean distances of the trials to test for significant treatment effect. Pairwise differences were used to evaluate interaction and order effects if main effects were found statistically significant.

## CHAPTER 4: RESULTS

### *Raw Individual Subject Data*

Table 2 represents the raw TCA data (means and standard deviations from the means) for each individual subject that was calculated using Matlab Software. The means presented on the table are the mean distances (in centimeters) from the subjects' mean point of contact.

Table 2

### *Means and Standard Deviations for Target Contact Accuracy*

| Subject | Group | Location | <u>Control</u> |        | <u>Rhythm</u> |        | <u>PSE</u> |        |
|---------|-------|----------|----------------|--------|---------------|--------|------------|--------|
|         |       |          | Mean           | SD     | Mean          | SD     | Mean       | SD     |
| 1       | A     | Near     | 0.2424         | 0.1160 | 0.0714        | 0.0341 | 0.1585     | 0.1039 |
| 1       | A     | Far      | 0.1460         | 0.0724 | 0.3715        | 0.1344 | 0.1657     | 0.0638 |
| 2       | A     | Near     | 0.3135         | 0.1001 | 0.4900        | 0.2656 | 0.8153     | 0.2052 |
| 2       | A     | Far      | 0.6119         | 0.2050 | 0.4994        | 0.2368 | 0.6187     | 0.4125 |
| 3       | B     | Near     | 0.4404         | 0.1768 | 0.2619        | 0.1371 | 0.3343     | 0.1749 |
| 3       | B     | Far      | 0.3555         | 0.1791 | 0.2583        | 0.0847 | 0.3483     | 0.1399 |

*Note:* Group A received the trials in the following order: Control, Rhythm, PSE. Group B received the trials in the following order: Control, PSE, Rhythm.

Table 3 represents the raw MAV data for each individual that was calculated using Matlab Software. The means presented on the table are the mean distances (in centimeters) from the subjects' mean midpoint ( $yz$  plane) of the trajectory path.

Table 3

*Means and Standard Deviations for Mid-Arc Variability*

| Subject | Group | Direction | <u>Control</u> |        | <u>Rhythm</u> |        | <u>PSE</u> |        |
|---------|-------|-----------|----------------|--------|---------------|--------|------------|--------|
|         |       |           | Mean           | SD     | Mean          | SD     | Mean       | SD     |
| 1       | A     | Flex      | 0.6629         | 0.1407 | 1.2013        | 0.9707 | 0.5759     | 0.3413 |
| 1       | A     | Ext       | 0.6058         | 0.2588 | 0.5761        | 0.1544 | 0.3672     | 0.2489 |
| 2       | A     | Flex      | 2.0063         | 1.3223 | 3.2391        | 1.0139 | 1.1873     | 0.4967 |
| 2       | A     | Ext       | 3.5807         | 2.9496 | 6.4224        | 4.317  | 1.5979     | 0.9551 |
| 3       | B     | Flex      | 0.4456         | 0.362  | 0.5354        | 0.4495 | 0.6005     | 0.3795 |
| 3       | B     | Ext       | 0.478          | 0.1698 | 0.7373        | 0.4075 | 0.6785     | 0.4191 |

*Note:* Group A received the trials in the following order: Control, Rhythm, PSE. Group B received the trials in the following order: Control, PSE, Rhythm.

*Statistical Analysis*

The data were imported from Excel 2007 and analyzed using SAS/STAT® software<sup>1</sup> for PC. The SAS software calculated a repeated measures ANOVA that was used to test for statistically significant treatment effects ( $p < .05$ ). The classification variables were listed as group, location and stimulus for target contact accuracy, and as group, direction, stimulus for mid-arc variability and the combinations therein. The response variables were accuracy and variability as it related to the mean standard deviations of the group, location/ direction and stimulus. A random statement was included which indicated that the subjects were random and determined if the accuracy

<sup>1</sup>SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc. in the USA and other countries. ® indicates USA registration.

scores were consistent enough to assume that additional subjects would perform in a similar manner. The least squared means statement identified the group, location/direction, and stimulus mean standard deviations. Pairwise comparisons would have been evaluated had the main effects been found statistically significant.

***Target Contact Accuracy Results***

The results for the stimulus (located in Table 4) were not found to be statistically significant as the calculated  $p=.5683$  was greater than the predicted  $p < .05$ . Group selection, order effects and location effects did not appear to be a factor in this study as they were both found to not be statistically significant (group  $p=.9156$  and location  $p=.6668$ ).

Table 4

*Target Contact Accuracy Repeated Measures ANOVA*

| Effect   | Num DF | Den DF | F value | Pr > F |
|----------|--------|--------|---------|--------|
| Group    | 1      | 1      | .02     | .9156  |
| Location | 1      | 10     | .20     | .6668  |
| Stimulus | 2      | 10     | .60     | .5683  |

*Note: \* $p < .05$ .*

The data presented in Table 5 indicated that the differences between the means of the three stimuli (control, rhythm, and PSE) were small (control mean=.3446, rhythm mean=.3184, and PSE mean=.3998). The PSE trial marginally demonstrated the most variance and the control indicated the least variance. The rhythm trial revealed less variability than the PSE trial. Because no statistically significant differences were found between the main effects, pairwise differences were not statistically relevant or needed



for the analysis.

Table 5

*Target Contact Accuracy Least Squared Means*

| Effect   | Group | Location | Stimulus | Estimate | Standard Error |
|----------|-------|----------|----------|----------|----------------|
| Group    | A     |          |          | .3754    | .1828          |
| Group    | B     |          |          | .3331    | .2585          |
| Location |       | Far      |          | .3680    | .1613          |
| Location |       | Near     |          | .3405    | .1613          |
| Stimulus |       |          | Control  | .3446    | .1642          |
| Stimulus |       |          | Rhythm   | .3184    | .1642          |
| Stimulus |       |          | PSE      | .3998    | .1642          |

***Mid-Arc Variability Results***

The differences found between the control and the PSE trial (table 6) were closer to being statistically significant in the mid-arc variability results ( $p=.1724$ ), however they were still determined to not be statistically significant ( $p < .05$ ). Group selection, location effects and order effects did not appear to have any statistically relevant influence in this study (group  $p=.6469$  and location  $p=.3476$ ).

Table 6

*Mid-Arc Variability Repeated Measures ANOVA*

| Effect   | Num DF | Den DF | F value | Pr > F |
|----------|--------|--------|---------|--------|
| Group    | 1      | 1      | .38     | .6469  |
| Location | 1      | 10     | .97     | .3476  |
| Stimulus | 2      | 10     | 2.11    | .1724  |

*Note: \*p < .05.*

Table 7 illustrates that the variability decreased substantially, nearly by half, from the control trial (mean=1.0872) to the PSE trial (mean=.6252). The sizable effect size but lack of statistical significance indicated substantial variability between the subjects. The rhythm only trial was the most variable of the trials with a mean of 1.9093, nearly double the control, but as with the previously mentioned trials, it was not statistically significant. It is notable that extension produced nearly twice the variance than flexion did, as would be expected (Extension mean=.1.4622, Flexion mean= .9523), yet not at a statistically significant level ( $p=.3476$ ). The lack of statistically significant main effect results indicated that pairwise differences were not relevant for the analysis.

Table 7

*Mid-Arc Variability Least Squared Means*

| Effect    | Group | Direction | Stimulus | Estimate | Standard Error |
|-----------|-------|-----------|----------|----------|----------------|
| Group     | A     |           |          | 1.8352   | 1.1704         |
| Group     | B     |           |          | .5792    | 1.6552         |
| Direction |       | Extension |          | 1.4622   | 1.0461         |
| Direction |       | Flexion   |          | .9523    | 1.0461         |
| Stimulus  |       |           | Control  | 1.0872   | 1.0776         |
| Stimulus  |       |           | Rhythm   | 1.9093   | 1.0776         |
| Stimulus  |       |           | PSE      | .6252    | 1.0776         |

Figure 1 illustrates the visible decrease in mid-arc variability in Subject Two's performance between the control trial and the PSE trial. As mentioned earlier, the rhythm trial was the most variable among the three trials and this finding is observable in Figure 1. (Conversely, the rhythm trial displayed less variance than the PSE trial in the target contact accuracy calculations. The rhythm target contact accuracy data can be viewed in Tables 2 and 5, as well as in Figure 3.) The black "X"s represent each midpoint of the five extension movements in each trial. The red circle represents the mean of the extension midpoints.

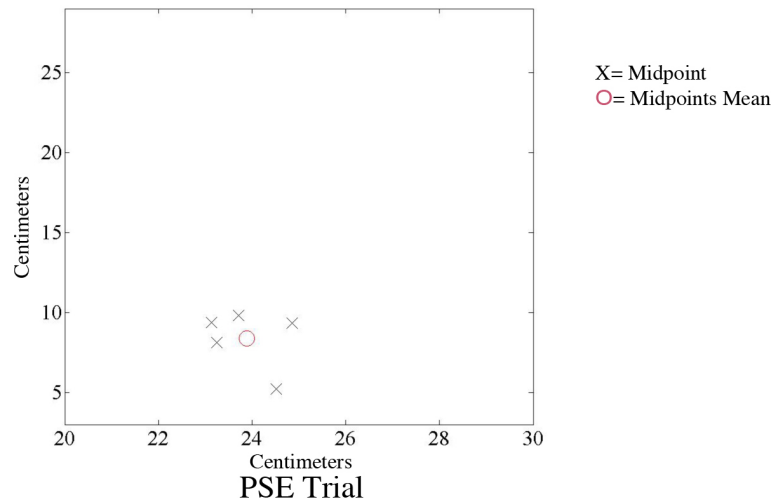
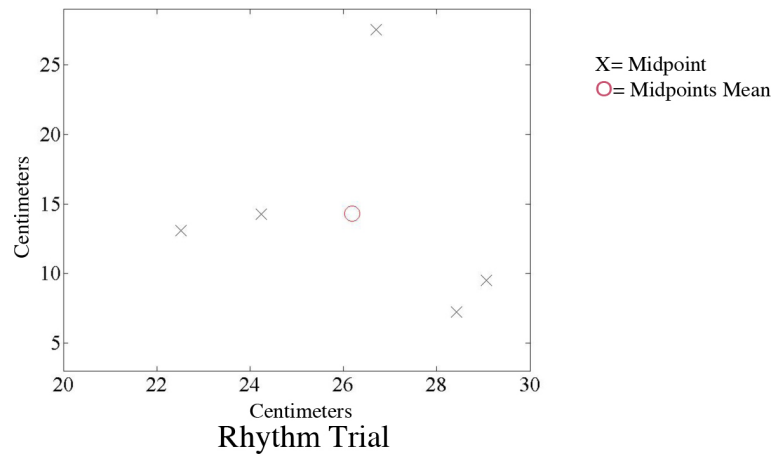
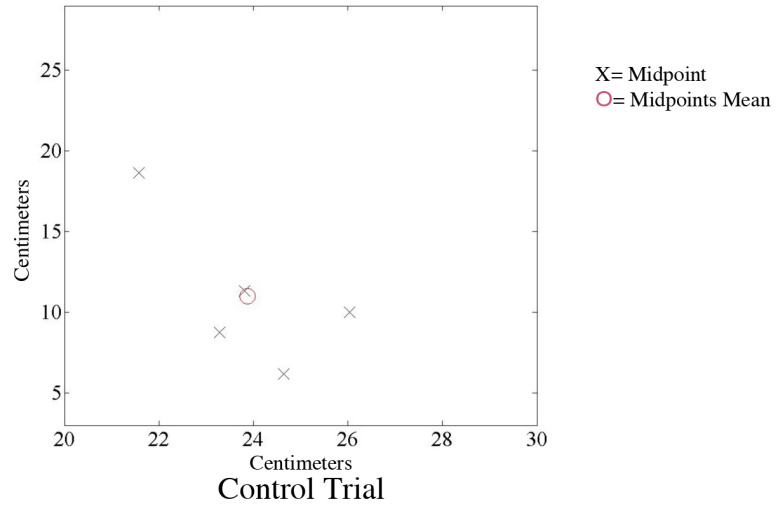
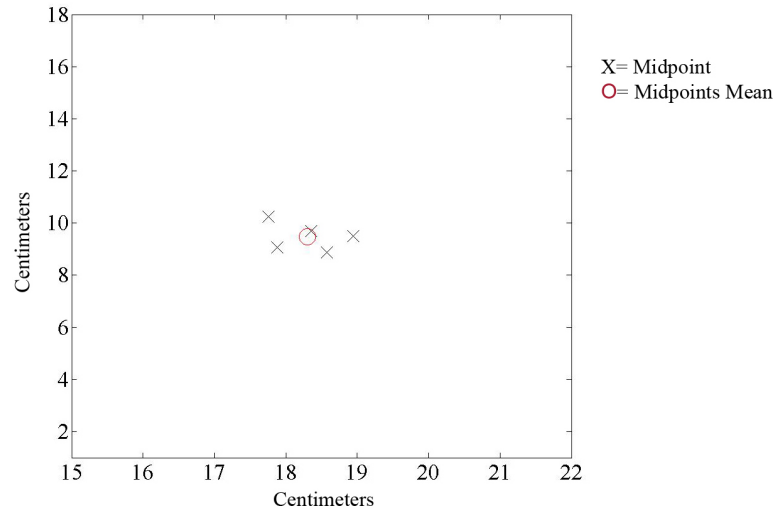
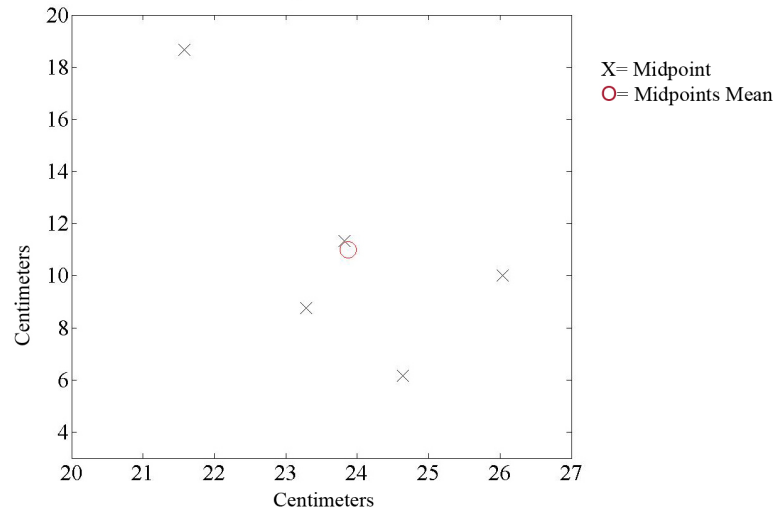


Figure 1. Mid-arc variability (Subject Two) during extension compared among the three trials: Control, Rhythm, and PSE.

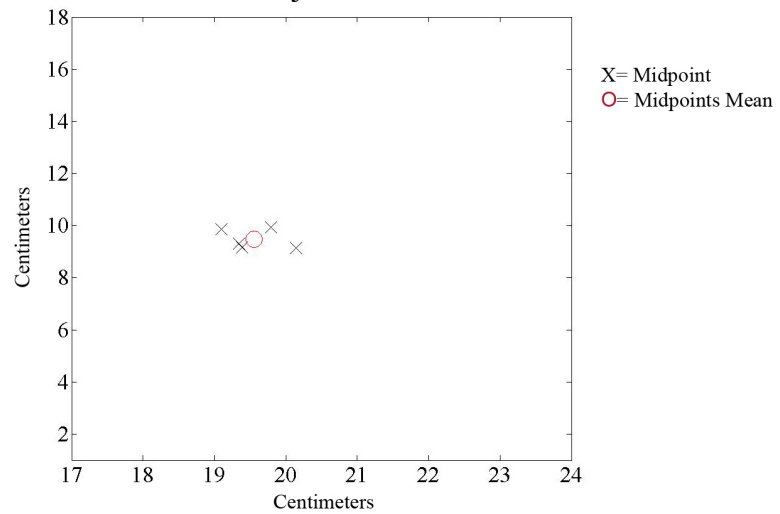
As mentioned previously, the substantial decrease in mid-arc variability between the control trial and the PSE trial but lack of statistical significance may likely be attributed to excessive variability between the subjects. Figure 2 illustrates the substantial baseline difference in performance between the three subjects mid-arc. Each graph identifies each midpoint of the five extension movements (black “X”) as well as the mean of the midpoints (red circle) during the control trial for Subject One, Subject Two, and Subject Three. Because the targets were positioned on the table depending on the comfort and arm length of the subject, the exact location relative to the graphed table varied. To establish a cohesive scale for the graphs, each graph is centered on a seven-centimeter x-axis and a 17-centimeter y-axis.



Subject One



Subject Two



Subject Three

Figure 2. Mid-arc variability of each subject in the control trial during extension.

Another interesting finding involves the contrast in variability when measuring target contact accuracy compared with mid-arc variability in the rhythm trials. It had been speculated that the control trial would be the most variable of the trials, followed by rhythm, with PSE being the least variable. It was observed in this study that when evaluating target contact accuracy, the PSE trial was most variable, followed by the control, and the rhythm trial was the most stable. This differed when measuring mid-arc variability. The mid-arc variability calculations revealed that the rhythm trial was the most variable, followed by the control, and the PSE trial was the most stable. Figure 3 displays the target contact accuracy of Subject One. The rhythm trial demonstrated more accuracy than the control at the near target, but less accuracy at the far target. The blue square represents the center of the copper target. The black “+”s convey each point of contact with the copper target in the trial, and the red circle symbolizes the mean of the points of contact. It is evident that there is about a one-centimeter error from the subject’s mean point of contact and the center of the target. It had been realized post-data collection, that the reflective marker which is attached to the fitted circuit connector protrudes forward one centimeter when the subject’s finger is slightly bent and is therefore the source of the error. This error was consistent across all of the subjects and all of the trials. Thus, it was determined that the evaluation of each subject’s mean point of contact and the distances from the subject’s mean point of contact were a better form of accuracy measurement than the distances from the center of the target. This error demonstrates the limitation of the technology available for this study and would not have been a factor if infrared technology were accessible.

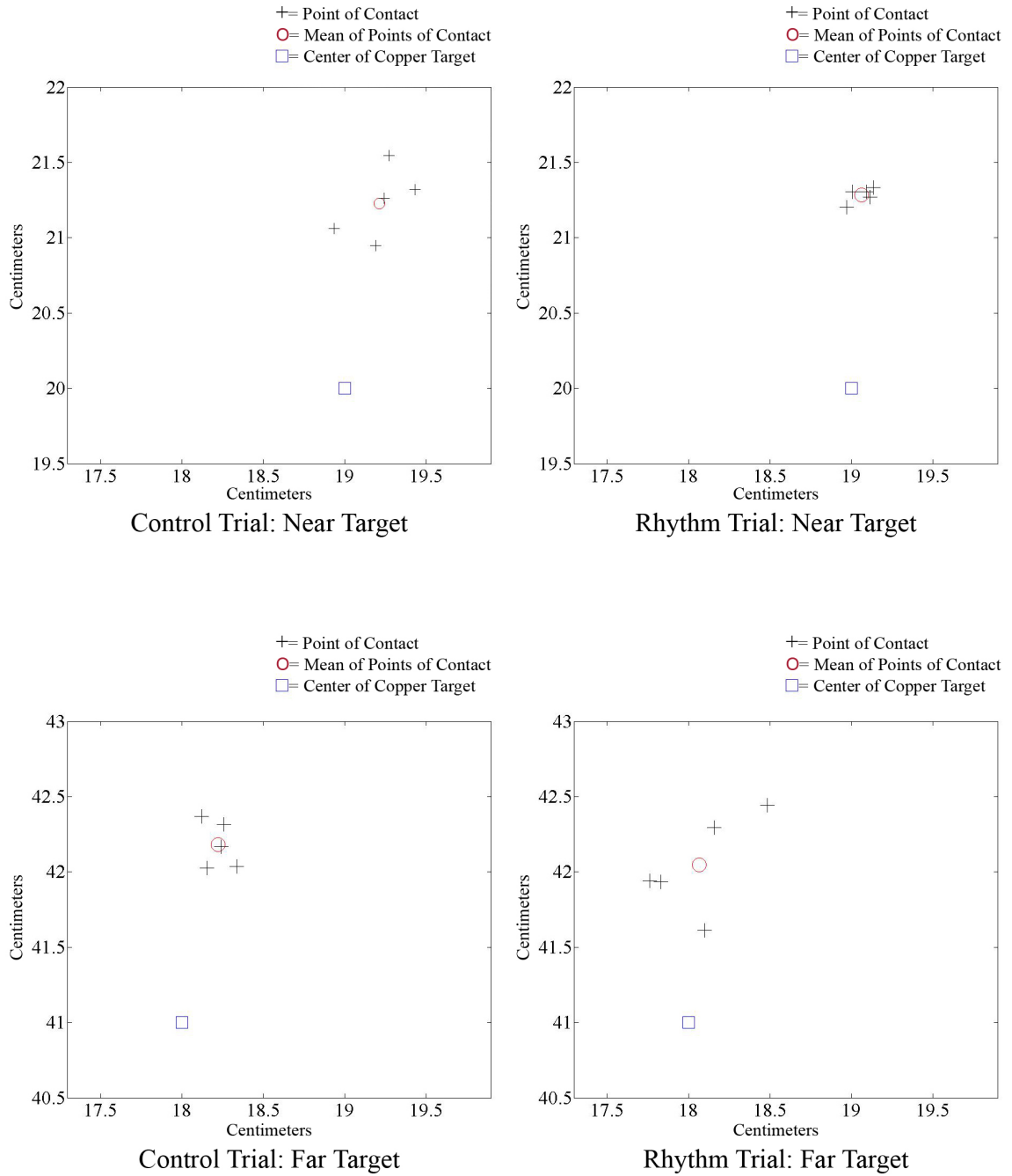


Figure 3. Target Contact Accuracy (Subject One) during the rhythm and control trials.

Although velocity calculations were not included in this study, listed below are each subject's total number of reaches per trial. Subject One completed 15 movements (extension and flexion combined) in the control trial (30 seconds), 12.5 in the rhythm trial



(30 seconds), and 16 in the PSE trial (30 seconds). Subject Two performed 11 movements in the control trial (30 seconds), 15 in the rhythm trial (30 seconds), and 15 in the PSE trial (30 seconds). Subject Three's disability was more severe, and he required 39 seconds to execute the necessary five complete movements in the control trial. In the rhythm trial, Subject Three completed five movements in 40 seconds, and he completed eight movements in 30 seconds in the PSE trial.

The results from this study indicate that target contact accuracy was not significantly affected by the two treatment trials. PSE did elicit less variability mid-arc, with nearly double the variance in the control trial than in the PSE trial. However, the results were not statistically significant, most likely due to excessive variability between the subjects. It is worth noting that an increased velocity was observed in one of the subjects during the PSE trial. The execution of the repetitive reaching movement was nearly twice as fast with the PSE stimulus than with rhythm alone, and no cueing (control). Yet, this data was not analyzed nor presented, as velocity was not initially planned to be a calculation in this study.

## CHAPTER 5: DISCUSSION

This study was proposed to determine if PSE would elicit more effective movement in hemiparetic upper limbs of persons that have had a stroke. It had been assumed that entrainment to a rhythmic auditory stimulus would produce less variability in a reaching movement compared to the same movement without rhythmic cueing. It had also been proposed that supplementing the auditory stimulus to include a force and spatial cue would produce even less variability than rhythm alone. The null hypothesis was not rejected, but the lack of statistically significant results may be attributed to factors associated with the small sample size and study design, not the treatment itself. Valuable information can still be gleaned from this pilot study in regards to what was learned during the course of this study. Adherence to recommended modifications for replication studies might produce different results.

As is, the data indicated that there were no significant differences in variability for target contact accuracy between the three trials (control, rhythm and PSE), and any differences that were discovered were most likely due to chance. The observed increase in velocity may have been a factor in the decreased target accuracy as increased velocity decreases the accuracy of an aimed movement (Bye & Neilson, 2008). This is an important consideration because the demands of various tasks and activities of daily living encountered by a person with a stroke may require *either* an increased velocity or an increased accuracy. If increased velocity is present in a task, decreased accuracy may be present as well. Conversely so, more accurate tasks might exhibit a decrease in velocity. It is recommended that velocity calculations be considered in future replication

studies and the various elemental requirements for effective movement be carefully considered.

The mid-arc variability results indicate some promising findings relating to the decrease in variability from the control trial to the PSE trial. The effect size was considerably substantial with the variance decreasing by nearly half in the PSE trial. This may indicate that PSE may have more effect on some kinematic parameters of movement than others. For example, PSE may improve variability during a movement but not the target accuracy of a movement. In contrast, rhythm alone may improve the target accuracy of a movement, but not the variability during a movement. The metronome provided brief and succinct auditory feedback for a targeted movement and this may be the reason that the target contact was more accurate with the rhythmic stimulus. PSE provided more long-term and continuous information about the complete trajectory path, and is perhaps why the mid-arc variability was the most stable during the PSE trial. As human movement is complex in a daily setting, this notion may be relevant and should be more specifically evaluated in future studies.

Another element to consider regarding the mid-arc variability results relates to the decrease in variability between the control and PSE trials but lack of statistical significance. This lack of significance is likely due to excessive variability demonstrated between the subjects. The substantial variability between subjects may have been caused by the lack of limitations set on stroke insult laterality, age, or level of existing disability. The laterality of stroke injury in the brain may have had an impact on their response to different aspects of the musical stimulus i.e., the rhythm, force (harmonic) or spatial (melodic) cue. Also, the subjects' age may have had an impact on their performance in

the study. Finally, the level of disability varied significantly between the three subjects, and it is likely this inconsistency most highly influenced the inter-subject variance and adversely affected the results. As such, it is highly recommended that future studies create boundaries regarding the laterality of the stroke, the subjects' age, and the level of disability of the selected subjects, and use a reliable and valid test to estimate disability. Additionally, it is recommended that the study design include several repetitions of each trial that can be averaged for each subject. These trial means may more accurately represent a person's consistent performance under each condition.

Another restriction of this study that prevented more conclusive results was the small sample size. It is acknowledged that the small sample size lacked the statistical power needed to determine a conclusive treatment effect. A substantial lack of resources prevented the use of a larger sample size and thus, was simply outside the scope of this project. The goal at the beginning of this research project was to recruit 15 or more participants. Several months were spent attempting to recruit subjects from the local hospital, rehabilitation clinics, and stroke support groups in the form of flyers and in-person presentations. Several specific delimitations of possible participants greatly reduced an already small pool of potential subjects. Furthermore, several stroke survivors and their families expressed that the months following a stroke are filled with many appointments and other commitments, and thus, fitting one more component into an already hectic schedule is simply outside the scope of possibility. It may be that providing some form of compensation for the participants' time may have helped recruitment. However, the lack of resources for this research project made it impossible to do so. Future studies conducted would need increased resources and larger sample

sizes to determine more conclusive results.

The limitations of technology and lab accessibility also posed a problem in this research project. Current and reliable technology is essential in order to ascertain conclusive and consistent results. The error that was observed in the target contact accuracy results relating to the size and location of the reflected marker on the fitted circuit connector demonstrates the limitations of technology in this study. Although substantial information can be gleaned using the subject's mean point of contact and the distances from the mean point of contact, supplementary measurements analyzing the distances from the center of the target would further enhance the information collected in a study. The use of infrared technology as opposed to reflective markers is highly recommended so that measurements could be taken not just on the subject's mean point of contact, but also how it relates to the center of the target.

Lab accessibility also poses as a potential confounder regarding accurate and consistent results. Although this problem wasn't experienced in this study, it is something that needs careful monitoring and consideration in future studies. The lab in which the equipment used for this study is located is also used for other music therapy groups and classes. Calibration of the spatial model is very sensitive and could be compromised if any of the cameras or the graphed table were nudged even slightly. It would be advisable to ensure that the calibrated equipment be in an undisturbed room to prevent calibration errors in future studies.

Final considerations for future studies involve the feasibility of the intervention itself. Providing consistent and systematic trials is essential for reliable and conclusive results. A systematic protocol was closely adhered to in this study and the establishment

of a similar protocol in future studies is advised. Utilizing a live stimulus (as opposed to a recording) to facilitate movement in a PSE intervention is one of the strengths of PSE. The auditory cueing in PSE can be adapted to each movement and each person depending on needs, goals, and disability. As such, comprehensive training from a qualified, skilled and knowledgeable professional is essential to provide the highest quality of intervention. Additionally, once the PSE intervention is appropriately researched and planned, the facilitator should practice the planned musical stimulus considerably prior to the first trial. These steps and considerations were adhered to in this study and enabled the PSE intervention to be applied systematically and effectively.

This pilot study was primarily conducted to gather data to be used in future studies. Even given the restraints of this study, promising information was revealed in this study. First, the use of PSE decreased mid-arc variability at a level that almost achieved statistical significance. The effect size from the control trial to the PSE trial nearly doubled, yet the inter-subject variability likely prohibited statistical significance. Second, the rhythm-only trial exhibited the most accuracy in the target contact accuracy calculations and the most variability in the mid-arc variability calculations. In contrast, the PSE trial displayed the most variance in the target contact accuracy trials and the most stability in the mid-arc variability calculations. These calculations did not achieve statistical significance, however, future studies that utilize suggested study design modifications might produce similar results at statistically significant levels. Lastly, Subject Two had the most severe disability of the three subjects and experienced the most improvement in stability in the PSE mid-arc variability calculations. He was also visually observed to double his velocity from the control and rhythm trials to the PSE trial.

However, since velocity calculations were not originally stated to be an element of measurement in this study, velocity calculations were not included in the analysis. The observed connection between level of disability and degree of improvement when employing PSE may indicate that PSE may be more effective with populations with more severe disability than with minor disability. It is recommended that this concept be further analyzed in future studies.

### *Conclusions*

Although the null hypothesis was not rejected in this study, important information was learned that can be used for future projects. The PSE intervention appeared to have more effect on mid-arc variability than it did on target contact accuracy. A decreased mid-arc variability was observed in the PSE trial, although not at a statistically significant level. The lack of significance is likely due to study design factors and inherent limitations rather than to the treatment itself. The related literature and findings of this study suggest that PSE may be a noninvasive, effective treatment and future studies are needed to determine a conclusive treatment effect. Limiting the level of disability, subject age, and laterality of the stroke while increasing the sample size may produce more statistically significant findings in future studies.

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## Appendix A

NOTICE OF APPROVAL FOR HUMAN RESEARCH

DATE: September 09, 2011  
TO: Lagasse, Blythe, 1778 Music Theatre Dance  
Queen, Todd, 1778 Music Theatre Dance, Lamb, Julia, 1778 Music Theatre Dance, Gondrez, Benjamin  
FROM: Barker, Janell, , CSU IRB 2  
PROTOCOL TITLE: THE EFFECTS OF PATTERNED SENSORY ENHANCEMENT ON HEMIPARETIC UPPER LIMB  
KINEMATICS  
FUNDING SOURCE: NONE  
PROTOCOL NUMBER: 11-2781H  
APPROVAL PERIOD: Approval Date: September 07, 2011 Expiration Date: June 17, 2012

The CSU Institutional Review Board (IRB) for the protection of human subjects has reviewed the protocol entitled: THE EFFECTS OF PATTERNED SENSORY ENHANCEMENT ON HEMIPARETIC UPPER LIMB KINEMATICS . The project has been approved for the procedures and subjects described in the protocol. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.

If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.

This approval is issued under Colorado State University's Federal Wide Assurance 00000647 with the Office for Human Research Protections (OHRP). you have any questions regarding your obligations under CSU's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to:

Janell Barker, Senior IRB Coordinator - (970) 491-1655 [Janell.Barker@Colostate.edu](mailto:Janell.Barker@Colostate.edu)  
Evelyn Swiss, IRB Coordinator - (970) 491-1381 [Evelyn.Swiss@Colostate.edu](mailto:Evelyn.Swiss@Colostate.edu)

Barker, Janell



Barker, Janell

Includes:

Amendment is approved to change the time limit post-stroke to include participants who have had a stroke more than six months ago. No change in risk level.

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Approval Period: September 07, 2011 through June 17, 2012  
Review Type: EXPEDITED  
IRB Number: 00000202

e-protocol

## Appendix B

**Consent to Participate in a Research Study  
Colorado State University**

**TITLE OF STUDY:** The Effects of Patterned Sensory Enhancement on Hemiparetic Upper Limb Kinematics

**PRINCIPAL INVESTIGATOR:** Blythe LaGasse, Ph.D., Assistant Professor, Department of Music, 970-491-4042, [Blythe.Lagasse@colostate.edu](mailto:Blythe.Lagasse@colostate.edu)

**CO-PRINCIPAL INVESTIGATOR:** Julia Uthe, Department of Music, Graduate Student, 970-302-9286, [juliauthe@gmail.com](mailto:juliauthe@gmail.com)

**WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?** You are invited to participate in a research study that evaluates music's effect on movement after a stroke. You would qualify for this study if you have had a stroke more than 6 months ago, have less than 5 years advanced musical training/ and or experience, and are experiencing some, but not complete paralysis in your arms.

**WHO IS DOING THE STUDY?** Julia Uthe will be doing the majority of the research with help from the research assistant Gary Kenyon and Julia's advisor, Blythe LaGasse.

**WHAT IS THE PURPOSE OF THIS STUDY?** The purpose of this study is to see how effective the Neurologic Music Therapy (NMT) technique called Patterned Sensory Enhancement (PSE) is on making a reaching movement with arms more efficient after a stroke. PSE uses the essential elements of music, rhythm, melody and harmony to help the brain plan and execute movements more effectively.

**WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?** The study will take place at in the Center for Biomedical Research in Music at Colorado State University. Your portion should take no more than a total of 1 hour of your time on one day.

**WHAT WILL I BE ASKED TO DO?** You will be seated comfortably in front of a graphed table and reflective sensors will be placed on your wrist, shoulder, and elbow. You will then be asked to alternately reach back and forth between a near target and a far target on the table at your own pace for 30 seconds. You will then rest for 2 minutes. Next, you will perform the same movement but will either tap the targets at the same time that you hear a steady metronome click, or a strum of an autoharp played by Julia. This tapping trial will also be 30 seconds long. Then you will rest for 2 minutes. Depending on if you tapped to the metronome or the autoharp in the previous trial, you will then do the movement to the other sound. Therefore, if you tapped to the metronome first, you would tap to the autoharp in the final trial and vice versa.

**ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?** You should not participate in this study if you have advanced musical experience/ skills, other health conditions that may cause you difficulty in the study, any other neurological disorders, if you are under the age of 18, or if your stroke occurred less than 6 months from the date of the study,

Page 1 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_\_

**WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?** You may experience some mild fatigue during the reaching movements (no greater than in ordinary daily life), but you will be given the opportunity to rest in between the 30-second trials.

- It is not possible to identify all potential risks in research procedures, but the researchers have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

**ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY?** There will not be any direct benefits to you for taking part in this study. The research study in general may provide more evidence for treatments such as Patterned Sensory Enhancement (PSE) that are non-invasive, effective ways to improve movement after a person experiences a stroke. We will be able to determine if adding a spatial and a force cue to a rhythmic cue will make a movement more effective.

**DO I HAVE TO TAKE PART IN THE STUDY?** Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

**WHO WILL SEE THE INFORMATION THAT I GIVE?** We will keep private all research records that identify you, to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key.

**WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?** No.

**WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH?** The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.

**WHAT IF I HAVE QUESTIONS?**

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Blythe LaGasse at 970-491-4042 or [Blythe.Lagasse@colostate.edu](mailto:Blythe.Lagasse@colostate.edu). If you have any questions about your rights as a volunteer in this research, contact Janell Barker, Human Research Administrator at 970-491-1655. We will give you a copy of this consent form to take with you.

This consent form was approved by the CSU Institutional Review Board for the protection of human subjects in research on September 7, 2011.

**WHAT ELSE DO I NEED TO KNOW?** Your trials will be videotaped for the sole purpose of analyzing the kinematic data using a computer program. Although videotaping will occur, there is no anticipated risk due to fact that the aperture on the camera is set so that someone cannot identify the participant (too dark, only markers visible) and the cameras will be focused on the arm, not the face. Therefore the person will not be identifiable in the video. After the research is completed and turned into digital information to be analyzed statistically, the videotapes will be erased.

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

\_\_\_\_\_  
Signature of person agreeing to take part in the study      \_\_\_\_\_  
Date

\_\_\_\_\_  
Printed name of person agreeing to take part in the study

\_\_\_\_\_  
Name of person providing information to participant      \_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of Research Staff

Page 3 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_\_