THERAPEUTIC INSTRUMENTAL MUSIC PERFORMANCE TO IMPROVE UPPER EXTREMITY FUNCTION IN PATIENTS WITH PARESIS AND APRAXIA AFTER STROKE

By

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M.M., Colorado State University, 2005

Submitted to the graduate degree program in Music Education and Music Therapy
and the Graduate Faculty of the University of Kansas
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Music Education (Music Therapy)

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Date Defended: May 14, 2018

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Chairperson: Cynthia Colwell, Ph.D.

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ABSTRACT

Therapeutic Instrumental Music Performance (TIMP) has been shown to improve upper extremity (UE) functions in stroke survivors. While numerous studies have examined stroke-induced paresis, research on stroke-related comorbid disorders remains limited, with relatively little consideration being given to the consequences of stroke. Ideomotor apraxia (IMA) is one such common post-stroke consequence that may hinder the purposeful UE action and movements necessary for the performance of daily living tasks. This study investigated the therapeutic potential of TIMP intervention to improve UE functions in post-stroke patients suffering concurrently from paresis and IMA. Seven left-hemisphere stroke patients with IMA participated in 9 individual 1-hour TIMP interventions over a period of 3 weeks. During each intervention, participants engaged in gross and fine motor exercises that primarily utilized drum and keyboard playing. All outcome measures were assessed at baseline, pretest, posttest and a follow-up test 3 weeks post-intervention. Clinical measures included the UE section of the Fugl-Meyer Assessment (FMA), Wolf Motor Function Test (WMFT), Box and Block Test (BBT), strength, ADL/IADL, and hand domains of the Stroke Impact Scale (SIS). The Apraxia Screen of TULIA (AST) was used to assess apraxic impairments. While therapeutic benefits varied, all UE functional levels of the participants demonstrated post-intervention improvements in gross and fine motor skills (FMA, WMFT, BBT) as well as perceived ADL skills (SIS). Moreover, such positive gains persisted for 3 weeks after the intervention. Participants continued to experience persistent IMA across the study timeline. The results of this study indicated that patients with post-stroke IMA were able to reap benefits from the TIMP intervention, as evidenced by improvement in their UE functions and perceived ADL skills despite the persistence of IMA. The findings of the study support the perception of TIMP intervention's

emerging efficacy in individuals suffering from post-stroke paresis and IMA, providing new information, implications and applications for both for researchers and clinicians. Rigorous future research is recommended to spur the development of efficacious and innovative rehabilitation interventions aimed at optimizing patient quality of care.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude to my advisor, Dr. Cynthia Colwell, for providing me with meticulous guidance and illuminating instruction while allowing me the autonomy to develop as an independent thinker. Her unflagging support and faith in my abilities sustained me throughout the course of my doctoral experience, and I will always be grateful for her patience, mentorship and encouragement, which have been a source of great strength during my maturation as a scholar and as an individual. She is an inspiration to my professional and personal life.

I am also grateful to all my committee members for their tremendous guidance and support. I would like to offer my sincere thanks to Dr. Andy Wu for his expertise and attentive mentoring throughout the research process, and especially for the time and sage advice he kindly offered during the study's participant recruitment. I am also truly grateful to Dr. Deanna Hanson-Abromeit, Dr. Christopher Johnson and Dr. Eva Horn for their discerning insights, constructive suggestions and sincere encouragement of my research.

Additionally, I owe a debt of gratitude to the staffs, therapists and stroke survivors at the American Stroke Foundation for their support and assistance, with special thanks to Dr. Dory Sabata, whose help and advice in the recruitment process proved to be of invaluable benefit. My heartfelt appreciation also goes out to all the study participants and their families for sharing their concerns, passion and earnest efforts, and without whom this study would not have been possible. My thanks as well to Amber Barclay for her help with data collection, Eric Shannon for statistical consultation, and Edward Kim for editing assistance.

I am also grateful to all of my past mentors and professional colleagues for their gracious support and inspiration.

I would like to express my utmost gratitude to my family and friends. I am so blessed to have been the recipient of their endless and unconditional support, encouragement, love and prayers. I certainly would not have reached this particular summit in my career without them.

Last but not least, I give thanks to God for granting me the opportunity and ability to pursue this wondrous and ongoing professional journey.

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CHAPTER 1

INTRODUCTION

Stroke remains the leading cause of adult long-term disability in the United States today, impacting these individuals with debilitating functional limitations (Go et al., 2014). Upper extremity (UE) paresis, in particular, is the most commonly occurring such impairment to be treated in post-stroke rehabilitation (Kwakkel, Kollen, & Wagenaar, 1999). Accordingly, the effectiveness of empirical treatment regimens targeting paresis has been well documented (Hatem et al., 2016; Kwakkel, Veerbeek, van Wegen & Wolf, 2015; Pollock et al., 2013). However, stroke survivors can also experience accompanying persistent stroke-related sequelae, which can further limit patients' performance of daily activities and thus reduce their quality of life (Young & Tolentino, 2009).

Ideomotor apraxia (IMA), a disorder affecting learned skilled movement, can occur even though the individual may retain sensory and motor functions, coordination, and language comprehension (Heilman & Rothi, 2003). IMA is a common consequence following a stroke, affecting up to roughly 54% of stroke survivors (Bickerton et al., 2012; Civelek, Atalay, & Turhan, 2015; Kaya, Unsal-Delialioglu, Kurt, Altinko, & Ozel, 2006; Zwinkels, Geusgens, van de Sande, & van Heugten, 2004). Temporal and spatial aspects of movement deficits, which are commonly associated with IMA, affect stroke patients on both sides of the body (Buxbaum, Shapiro, & Coslett, 2014; Hermsdorfer, Hentze, & Goldenberg, 2006; Leiguarda, 2001; Mutha, Sainburg, & Haaland, 2010; Poizner et al., 1995). IMA thus adversely impacts such patients' UE functions and hinders the performance of functional purposeful actions required for daily living tasks (Bienkiewicz, Brandi, Goldenberg, Hughes, & Hermsdorfer, 2014; Hann-Pladdy, Heilman, & Foundas, 2003; Sunderland & Shinner, 2007).

Moreover, recent additions to the literature highlight the persistent nature of IMA impairments (Bickerton et al., 2012; Donkervoort, Dekker, & Deelman, 2006). Further studies have also indicated that stroke patients with IMA derive fewer benefits from traditional rehabilitation efforts than those without IMA, suggesting the importance of continuous treatment for successful rehabilitation outcomes (Civelek et al., 2015; Unsal-Delialioglu, Kurt, Kaya, Culha, & Ozel, 2008; Wu, Burgard, & Radel, 2014). Citing such shortcomings in therapeutic interventions for IMA, numerous researchers have further emphasized the dearth of studies involving this patient population and have encouraged the development of innovative, efficient rehabilitation approaches to address the needs of these patients (Buxbaum et al., 2008; Cantagallo, Maini, & Rumiati, 2012; Cicerone et al., 2005; Dovern, Fink, & Weiss, 2012; West, Bowen, Hesketh, & Vail, 2008).

One notable emerging rehabilitative approach, Neurologic Music Therapy (NMT), is grounded in evidence-based practices and has been employed in research and clinical settings over the last two decades to treat motor dysfunctions in post-stroke patients (Homberg, 2013; Thaut, 2005; Thaut & McIntosh, 2014). Within the NMT context, Therapeutic Instrumental Music Performance (TIMP), in particular, is an essential motor rehabilitation technique based on the motor-learning and feedback/feedforward principles (Thaut, 2005). TIMP utilizes the playing of musical instruments designed for therapeutic purposes to facilitate targeted non-musical functional movement patterns that promote efficient daily life functioning (Thaut, 2005; Mertel, 2014). Numerous studies have provided a rigorously compiled foundation of evidence demonstrating the strong auditory-motor interconnectivity and the potential for deploying musical elements as a medium for motor rehabilitation (Bangert & Altenmuller, 2003; Bangert et al., 2006; Harrington, Haaland, & Knight, 1998; Konoike et al., 2012; Lahav, Saltzman, &

Schlaug, 2007; Thaut & Kenyon, 2003; Tierney & Kraus, 2013; Zatorre, Chen, & Penhune, 2007). Notably, researchers have accumulated neural and clinical evidence that arm-training in conjunction with music playing can activate cortical connectivity and increase activation of auditory-motor couplings in stroke patients (Altenmuller, Marco-Pallares, Munte, & Schneider, 2009; Fujioka, Ween, Jamali, Stuss, & Ross, 2012; Grau-Sanchez et al., 2013; Jamali, Fujioka, & Ross, 2014; Ripolles et al., 2016; Rodriquez-Fornells et al., 2012; Rojo et al., 2011). Meanwhile, other studies have shown that TIMP can produce salutary effects in stroke patients' UE functions and functional independence by treating their paresis (Schneider, Munte, Rodriquez-Fornells, Sailer, & Altenmuller, 2010; Schneider, Schonle, Altenmuller, & Munte, 2007; Street et al., 2018; Tong et al., 2015; van Vugt, Ritter, Rollnik, & Altenmuller, 2014; Villeneuve, Penhune, & Lamontagne, 2014; Yoo, 2009, 2015). To date, however, researchers have paid comparatively little attention to stroke-related comorbid disorders in the field of music therapy.

Recognizing underlying impairments and employing rigorous therapeutic mechanisms to improve individuals' lives are essential tasks for clinicians (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996). Music therapists regularly treat clients suffering from a wide range of functional abilities that may need specialized rehabilitation efforts. Such efforts often encompass more focused and prolonged care when the patient suffers from underlying difficulties such as comorbid disorders. In light of IMA's demonstrated adverse impacts on motor performance and daily functioning (Bienkiewicz, et al., 2014; Hann-Pladdy et al., 2003; Sunderland & Shinner, 2007), the current literature has underlined the need to develop efficient rehabilitation methods for post-stroke IMA patients (Cicerone et al., 2005; Dovern, et al., 2012; West et al., 2008). However, despite the high incidence of post-stroke IMA (Civelek et al., 2015; Kaya et al., 2006), the disorder's potential impacts generally receive limited attention in the clinical/rehabilitation setting, with less consideration given to the consequences of stroke. This, in turn, has severely limited investigation into the promising benefits of the therapeutic use of music in stroke rehabilitation, an oversight that the present study seeks to address.

As previous researchers have already assessed IMA to be a persistent disorder affecting stroke patients (Bickerton et al., 2012; Donkervoort, et al., 2006), it is not the intent of this study to propose an IMA-focused treatment regimen. Rather, the present research seeks to investigate stroke rehabilitation outcomes while considering the presence of IMA. Thus, this pilot study, as an initial exploration into stroke-related comorbidity, primarily focuses on examining the potential of TIMP to improve UE motor functions in individuals suffering from post-stroke paresis and IMA. As suggested by previous evidence supporting TIMP's positive neural and clinical effects on paresis in stroke patients, TIMP may provide benefits to stroke survivors suffering concurrently from paresis and IMA. In the case of IMA patients who have difficulty performing targeted actions, prior research has shown that during clinical musical experiences, the temporal auditory patterns that patients played on musical instruments and the sequentially patterned musical cues in the music can improve patients' anticipatory planning and execution of motor performance (Thaut, 2015; Thaut & McIntosh, 2014). Additionally, the experience of successfully playing music has been shown to increase stroke patients' motivation and repetition of movements by providing an enjoyable and rewarding experience (Raghavan et al., 2016; van Vugt et al., 2014). Such functional and motivational effects of music may thus facilitate the therapeutic benefits that patients with IMA receive from treatment efforts.

With this in mind, the purpose of the present study was to examine the changes in UE functions following the completion of TIMP intervention in post-stroke patients concurrently exhibiting from paresis and IMA. This study thus sought to contribute to the stroke rehabilitation literature and clinical practice by exploring the potential for music therapy intervention, specifically TIMP, to provide a successful rehabilitative method for stroke-related sequelae. Indeed, these research findings may further serve as the basis for future investigation of this patient population and the development of music therapy intervention for optimal rehabilitation efforts.

CHAPTER 2

REVIEW OF LITERATURE

This literature review will provide an overview of past and current studies on the therapeutic use of music to address consequent stroke-related disorders such as apraxia. The review begins with an examination of apraxia, especially IMA, highlighting the neuroanatomical evidence related to apraxia and the development of explanations for apraxia etiology. Next follows a description of practical real-life impacts, including physical and functional upper extremity (UE) challenges and current rehabilitation methods for post-stroke IMA outside the music therapy field. Finally, this review presents current evidence concerning the outcomes of music therapy application, specifically those using TIMP, in the context of stroke rehabilitation. Specifically, this section discusses the basic foundations of rhythm and music in motor rehabilitation, prior studies focusing on the capacity of TIMP to improve UE function in stroke patients, and an additional therapeutic rationale linking music and extant stroke rehabilitation outcomes to post-stroke consequences such as IMA. This literature review will thus identify significant implications for future research, including the need to conduct IMA-related efficacy studies.

Apraxia

Apraxia is generally defined as the inability to perform a purposeful, skilled, learned movement due to factors that cannot be attributed to elementary motor or sensory deficit, language comprehension impairment, or inattention (De Renzi, 1989; Heilman & Rothi, 2003). Belonging to a higher order of movement disorders, apraxia is not explained by elementary motor disorders such as weakness, rigidity, tremors, ataxia, dystonia or chorea (De Renzi, 1989; Heilman & Rothi, 2003). Apraxia can typically be observed when a patient is verbally directed to perform a gesture with a limb (i.e., pantomiming both tool-related and communicative gestures), to imitate other person's gestures, to carry out the appropriate movement in response to a visually presented object, or to complete an action using the actual object (De Renzi, Motti, & Nichelli, 1980; Heilman & Rothi, 2003; Vanbellingen et al., 2010). Both the completion of meaningless gestures (e.g., imitating a novel gesture such as laying an index finger atop the nose) and gesture recognition have been suggested as methods to test for indications of apraxia (Vanbellingen et al., 2010).

Ideomotor Apraxia

While the umbrella of apraxia covers several variants of the disorder involving the upper extremities (UE), the most widely recognized type of apraxia is ideomotor apraxia (IMA) (Petreska, Adriani, Blanke, & Billard, 2007; Wheaton & Hallett, 2007), which is the focus of the current study. IMA disrupts the 'production' component of praxis (the ability to perform purposeful, skilled movement) while such skilled movement comprises two components: the sensorimotor action 'planning' (generating the sensorimotor representation of the action) and 'execution' or 'production' (the mechanism for movement control) (Petreska et al., 2007). Accordingly, patients with IMA are commonly characterized by their tendency to make spatial and temporal errors (Heilman & Rothi, 2003; Leiguarda, 2001; Poizner et al., 1995; Poizner, Mack, Verfaellie, Rothi, & Heilman, 1990; Rothi, Ochipa, & Heilman, 1991). Spatial errors include impaired positioning of the hand in an appropriate posture, incorrect orientation of the body part targeted to perform the action, abnormal amplitude of an action, and failure to coordinate joint movement (Buxbaum et al., 2014; Haaland, Harrington, & Knight, 1999; Hermsdorfer et al., 2006; Manuel et al., 2012; Mutha et al., 2010; Poizner et al., 1995). Patients with IMA frequently display body part as object errors (i.e., using a body part as a specific object rather than demonstrating the use of the object) (Manuel et al., 2012; Raymer, Maher, Foundas, Heilman, & Rothi, 1997). For instance, when being asked to pretend to brush his teeth, the patient may use his own finger instead of the imagined toothbrush (body part as object error), make a fist tightly without preserving a space for the imagined toothbrush (internal configuration error) or hold the imagined toothbrush next to the eyes instead of the mouth (external configuration, orienting errors). IMA is also associated with deficits in timing (e.g., abnormal speed or control of movement) or sequencing (e.g., addition, deletion or transposition of movement elements) features of movement (Haaland et al., 1999; Heilman & Rothi, 2003; Weiss, Rhbari, Hesse, & Fink, 2008).

Patients with IMA may also exhibit different degrees of impairment depending upon testing conditions. Earlier studies have already shown that patients typically encounter greater difficulty performing under testing conditions but spontaneously perform better in natural contexts (De Renzi, Faglioni, & Sorgato, 1982; De Renzi et al., 1980; Hanna-Pladdy, Heilman, & Foundas, 2001; Leiguarda & Marsden, 2000; Petreska et al., 2007; Schnider, Hanlon, Alexander, & Benson, 1997). Such voluntary-automatic dissociation can be mitigated with contextual and situational cues (De Renzi et al., 1982; Halsband et al., 2001) or visual and tactile cues (Goldenberg, 2001; Hermsdorfer et al., 2006; Ietswaart, Carey, & Della Sala, 2006). In addition to context, gesture type may cause various performance impairments. For example, patients exhibit greater impairments when verbally prompted to perform gestures (e.g., "pretend to brush your teeth while holding a toothbrush"), but they encounter less difficulty imitating or performing actions in response to a visually presented object (De Renzi et al, 1982; De Renzi et al., 1980; Hanna-Pladdy, Heilman, & Foundas, 2001; Ochipa, Rothi, & Heilman, 1994). The type of gesture also influences different results for actions, as transitive gesture movements (i.e., those involving tool/object use) seem to be more affected than intransitive ones (i.e., communicative gestures not involving tool/object use) in pantomiming (Leiguarda & Marsden, 2000). However, previous research has shown that there is a disassociation between transitive and intransitive movements (Stamenova, Roy, & Black, 2010).

Since patients may be least impaired when using a real object, they are often considered to be performing the same action without experiencing deficiencies in their real daily life (De Renzi et al., 1980). However, a variety of recent studies refutes these seemingly typical findings by pointing out the functional challenges that apraxia poses for the performance of daily tasks (Bjorneyby & Reinvang, 1985; Civelek et al., 2015; Donkervoort et al., 2006; Foundas et al., 1995; Goldenberg, Daumuller, & Hangman, 2001; Hanna-Pladdy et al., 2003; Sunderland, Walker, & Walker, 2006; Sundet, Finset, & Reinvang, 1988; Unsal-Delialioglu et al., 2008; Walker, Sunderland, Sharma, & Walker, 2004; Weiss et al., 2008; Wu et al., 2014). These apraxia-derived functional challenges are discussed further in a subsequent section of this literature review.

IMA is often compared to ideational apraxia and conceptual apraxia. Patients with ideational apraxia demonstrate an inability to correctly perform a sequence of actions (e.g., making a cup of tea). Examples of such inabilities could involve executing an action out of order or missing a step, even though the patient recognizes how to perform a sequential task (Heilman & Rothi, 2003). Patients with conceptual apraxia, meanwhile, exhibit deficits of object/tool knowledge, contributing to difficulty using an object, performing an action associated with the object, or utilizing the mechanical advantages of the object (Heilman & Rothi, 2003; Ochipa, Rothi, & Heilman, 1992). Ideational apraxia and conceptual apraxia are known to arise from disruptions in the conceptual component of action (Heilman & Rothi, 2003). It is thus generally agreed that, in the case of performing a purposeful movement, patients with ideational or conceptual apraxia do not know what to do (difficulty with recognition), whereas patients with IMA know what to do, but do not know how to perform the action (difficulty with execution) (Buxbaum, 2001; Heilman & Rothi, 2003; Wheaton & Hallett, 2007; Zadikoff & Lang, 2005).

Neuroanatomical Aspects of Apraxia

Apraxia has long been considered to be connected with functions of the left hemisphere. For example, lesions of the left hemisphere have been linked to injuries that occur more frequently or in greater severity than right-hemisphere injuries. Accordingly, a variety of apraxia studies have addressed this left-hemisphere dominance (De Renzi et al., 1980; Flores-Medina, Chavez-Oliveros, Medina, Rodriquez-Agudelo, & Solis-Vivanco, 2014; Haaland, Harrington, & Knight, 2000; Hanna-Pladdy & Daniels et al., 2001; Stamenova et al., 2010). However, praxis (i.e., the ability to perform purposeful movement) is also associated with regions of the right hemisphere, suggesting the involvement of the right hemisphere in cases of apraxia (De Renzi et al., 1980; Stamenova et al., 2010). Several studies have reported impairments in both hemispheres, a finding that suggests that apraxia occurs bilaterally and is widespread and distributed across both hemispheres, rather than being localized in specific regions (Flores-Medina et al., 2014; Haaland et al., 2000; Hanna-Pladdy & Daniels et al., 2001; Hanna-Pladdy, Heilman, & Foundas, 2001; Roy et al., 2000).

Earlier research has suggested that hemisphere dominance may depend upon the context in which an action is performed, or upon whether the task type involves cognitive demands (Flores-Medina et al., 2014; Leiguarda & Marsden, 2000). For instance, patients with left-hemisphere damage exhibit greater impairment when performing in the abstract (e.g., pantomiming) than when using actual objects; others suffer performance deficits in testing situations, but perform better under real-life daily conditions (Rapcsak, Ochipa, Beeson, & Rubens, 1993; Schnider et al., 1997). Higher complex movement, including the planning and sequencing of movements or the selecting and shifting of motor attention, has generally been regarded as a process of the left hemisphere (Roy & Square, 1994; Rushworth, Nixon, Renowden, Wade, & Passingham, 1997). The types of movement related to tool/object use may also differ in hemisphere representation. Tasks requiring intransitive movement, for example, generate greater activation of the left hemisphere of the brain, whereas tasks requiring transitive complex movement involve a bilateral distribution of brain activation (Flores-Medina et al., 2014). Selective impairments for transitive gestures were more frequent following right-hemisphere damage, while most deficits (e.g., intransitive, transitive, pantomime, imitation) were pronouncedly more impaired in patients with left-hemisphere damage (Stamenova et al., 2010).

In addition to examining hemisphere dominance, a number of studies have also tried to localize IMA (i.e., identify specific regions related to apraxia) in cortical areas. IMA has primarily been associated with damage to the brain's parietal and frontal areas and to their deeper subcortical connections (Bienkiewicz et al., 2014; Haaland et al., 2000). The literature brims with studies reporting on IMA's relation to the parietal lobe, specifically, the inferior parietal lobe (IPL), including the angular gyrus and supramarginal gyrus (close to Broadmann Area (BA) (Brodmann, 2006) 39, 40) (Buxbaum et al., 2014; Buxbaum, Kyle, Grossman, & Coslett, 2007; Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; Goldenberg, 2009; Haaland et al., 1999, 2000; Halsband et al., 2001; Leiguarda & Marsden, 2000; Randerath, Goldenberg, Spijkers, Li, & Hermsdorfer, 2010), and the posterior parietal cortex, including the superior parietal lobe (SPL) (BA, 5, 7) (Bolognini et al., 2015; Convento, Bolognini, Fusaro, Lollo, & Valla, 2014; Haaland et al., 1999; Heilman, Rothi, Mack, Feinberg, & Watson, 1986).

Earlier studies have argued that damage to the parietal cortex interferes with a range of actions, including generating mental representations of movements (Buxbaum et al., 2003; Heilman, Rothi, & Valenstein, 1982; Sirigu et al., 1996), motor planning, guiding and execution (Convento et al., 2014), preparing and redirecting (switching) intended movements (Rushworth & Taylor, 2006; Rushworth, Krams, & Passingham, 2001), performing gesture tasks and tool use (Buxbaum et al., 2014; Buxbaum et al., 2007), and integrating internal mental representations and spatiomotor information processing involving body configuration (Binkofski & Buxbaum, 2013; Buxbaum et al., 2007; Buxbaum et al., 2003; Goldenberg & Karnath, 2006; Haaland et al., 1999).

Apraxia studies have frequently observed how damage within the frontal lobe, specifically a premotor cortex (BA lateral 6) lesion, can influence the patient's selection of appropriate movement (Rushworth, Johansen-Berg, Gobel, & Devlin, 2003) and affect temporal aspects of movement (Halsband, Ito, Tanji, & Freund, 1993). Other researchers have demonstrated the association between a supplementary motor area (SMA) (BA medial 6) and apraxia (Halasband et al., 2001; Watson, Fleet, Rothi, & Heilman, 1986), affecting the patient's process of translating a transformation movement plan into an appropriate motor action (Heilman & Rothi, 2003; Rothi et al., 1991).

Studies have also suggested that lesions in the inferior frontal gyrus, including Broca's area, are linked to apraxia (Alexander, Baker, Naeser, Kaplan & Palumbo, 1992; Bienkiewicz et al., 2014; Goldenberg & Karnath, 2006; Rushworth et al., 2001). This particular region of Broca's area (BA 44) in humans may be homologous to region F5 in monkeys, which contains 'mirror neurons,' and is thought to be devoted to specific sensorimotor transformation, i.e., the activation of mirror neurons for both action observation and execution (Rizzolatti & Craighero, 2004; Rizzolatti, Luppino, & Matelli, 1998). Such visuomotor transformation deficits are often observed in patients with apraxia when they attempt gesture imitation (Buxbaum, Kyle, & Menon, 2005; Goldenberg & Karnath, 2006).

Considering the anatomical relation and similar deficits produced between parietal and frontal areas, researchers have further explored larger contexts of the fronto-parietal network (Haaland et al., 1999, 2000). For example, in one brain imaging study, Haaland and her colleagues (2000) identified areas around the left middle frontal gyrus (BA 9, 46, 6, 8) and left intraparietal sulcus (BA 7, 39, and 40) as regions associated with apraxia; those regions have been shown to be responsible for the execution of goal-directed movements (Haaland et al., 2000) and spatial motor transformation processing (Buxbaum, 2001; Buxbaum et al., 2007). The involvement of the left frontal and parietal regions in apraxia has been supported by other studies as well (Bienkiewicz et al., 2014; Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005; Hanna-Pladdy, Heilman, & Foundas, 2001; Moll et al., 2000).

In addition to damaging cortical areas, apraxia may also occur following lesion formation in subcortical white matter tracts, including in the arcuate fasciculus (Geschwind, 1965) or corpus callosum (Watson & Heilman, 1983); lesions in the arcuate fasciculus may result in disrupted connections between the cortical areas involved in sensory systems (Wernicke's area), while lesions in the corpus callosum may spawn deficits in motor processing (ipsilateral or contralateral movement). The basal ganglia, via surrounding white matter tracts and connections with the frontal-parietal cortex, also plays an important role in apraxia occurrence, affecting timing and sequencing, sensorimotor transformation or selection, and direction of appropriate motor programs (Leiguarda, 2001; Zadikoff & Lang, 2005).

Researchers have further suggested interplay between apraxia and widely distributed, larger-scale networks of cortical and subcortical areas (Hanna-Pladdy, Heilman, & Foundas, 2001; Roy et al., 2000), but the findings remain inconclusive. Indeed, related studies have pointed to the inherent difficulty of localizing and identifying the specific location, size or severity of a given lesion and of identifying the contributing effects on disorders (Buxbaum et al., 2014; Haaland et al., 2000; Hanna-Pladdy, Heilman, & Foundas, 2001; Leiguarda & Marsden, 2000; Roy et al., 2000).

Development of Concepts of Apraxia

Several neuropsychological explanations have been proposed concerning the foundations of apraxia. The first contemporary idea of apraxia arose from the work of Liepmann (1920), who posited that the representation of movement, called "movement formulae" (i.e., the spatiotemporal plan of an action), is stored in the left parietal lobe, supporting the theory of left-hemisphere dominance (Goldenberg, 2003). For a skilled movement to occur, the brain must retrieve an image of the spatial and temporal components of an action and associate it with a muscle innervation pattern in order to execute the correct positioning of body parts, activating the left premotor and primary motor areas for right-side movement. Further, this activation can be transferred to right-side premotor areas via the corpus callosum for the performance of left-arm movements. Liepmann argued that IMA resulted from the disconnection of frontoparietal connections indicating that the movement idea was intact but unable to be translated correctly into a physical act (Goldenberg, 2003).

Expanding on Liepmann's interpretations, Geschwind (1965) proposed a more specific left-hemisphere dominance model based on the disconnection between motor and language areas. He suggested that carrying out movements in response to a verbal command required the involvement of the left-hemisphere language mechanism. Under this postulation, the information contained in a language-impelled action first registers in Wernicke's area before being transferred to the left motor association cortex (via the arcuate fasciculus) and left primary cortex for the control of right-hand movement. For the control of left-hand movement, information needs to be transmitted (via the corpus callosum) to the right-side motor association cortex. Disconnection thus occurs during the interruption of the translation of language areas (sensory input) into left- and right-side motor cortices.

Subsequently, several researchers developed dual-component models by incorporating conceptual information and spatiomotor processing to assess action performance (Buxbaum, 2001; Heilman et al., 1982; Rothi et al., 1991; Roy & Square, 1985). Roy and Square (1985) proposed a two-part model in which praxis can be divided into two separate subsystems – conceptual and production systems. The conceptual system involves abstract representation of the actions and knowledge of 1) objects and tool use, 2) actions independent of tool or object use, and 3) sequencing a series of single actions. On the other hand, the production system contains 1) a sensorimotor component of information on how to perform a programmed (organized) action, which requires a high level of production-demanding attention skills, as well as 2) mechanisms of motor control processes for the execution of the action. Ideational apraxia and IMA arise from deficits in the conceptual system and production system, respectively. Roy (1996) subsequently extended this model to consider three systems in the control of movement: 1) the sensory/perceptual system, which processes visual, auditory, and tactile information from the environment, 2) the conceptual system, which stores knowledge about tools and actions, and 3) the production system, which includes several subsystems serving various functions such as response selection, image generation, working memory storage of the motor plan and response organization and control of movement (Roy, 1996).

In a similar vein, another influential model proposed by Heilman, Rothi and their colleagues (Heilman et al., 1982; Rothi et al., 1991) can account for several possible dissociations in complex human praxis performance. This model identified the possibility of separate systems for the recognition (receptive aspect) and production (expressive aspect) of action; modality-specific dissociations corresponding to different sensory inputs (e.g., visual, auditory, verbal); conceptual knowledge and memory (action semantics) related to tools/objects/actions and seen in counterpoint to dissociations with other subsystems; and separate action routes for the imitation of novel and meaningless gestures. This model argued that 'visuokinematic motor engrams' – a concept compatible with Liepmann's 'movement formulae' – were stored in the left inferior parietal lobe (IPL) (Heilman et al., 1982; Rothi et al., 1991). The fact that gesture production could be dissociated from gesture recognition resulted in the proposal of two forms of IMA: the anterior-production form and the posterior-conceptual/representational form. In the former, damage to anterior areas impaired only gesture production, while in the latter, patients with posterior lesions demonstrated impairments in comprehension as well as in the production stages of the action (Heilman et al., 1982).

Buxbaum and her colleagues extended Rothi's findings on praxis by stressing the role of body knowledge, 'body schema' (body part positioning in relation to other body parts involved in the action) (Buxbaum, Giovanetti, & Libon, 2000), and how such knowledge can be translated into action (Buxbaum, 2001; Buxbaum et al., 2000; Buxbaum et al., 2007). This model listed the processes of 1) internal representations of movements (stored conceptual semantic knowledge), which might be processed by the ventral stream, and 2) spatial motor transformation processing based on the body- centered coding, which might be processed by the dorsal stream. According to this explanation, damage to such processes can prevent gesture representation from transforming into motor programming execution by scrambling information about current and targeted body part positions (Binkofski & Buxbaum, 2013; Buxbaum, 2001; Buxbaum et al., 2007; Leiguarda & Marsden, 2000).

Other researchers have used such body part coding to seek a better understanding of impaired gesture imitations or tool uses in the apraxia context (Goldenberg, 2014; Goldenberg & Karnath, 2006). Their studies, however, proposed an alternative approach to that of earlier cognitive models, arguing that apraxia may not fully be explained by concepts based on the processes of perception (semantic knowledge) and action (Binkofski & Buxbaum, 2013; Buxbaum, 2001; Rothi et al., 1991). Instead, these researchers held that the disorder was linked to disrupted problem solving and the functional capabilities of the objects/tool (Goldenberg, 2014; Goldenberg & Spatt, 2009; Hodges, Spatt, & Patterson, 1999; Spatt, Bak, Bozeat, Patterson, & Hodges, 2002; Osiurak, Jarry, & Le Gall, 2011; Osiurak, Jarry, Lesourd, Baumard, & Le Gall, 2013). According to this argument, apraxia may disrupt the processing of practical information about tools and objects based on perceptual attributes (topographical knowledge) (Goldenberg, 2014). Such an inability to reason out the objects' physical properties could thus impair problem-solving strategies in matters of both comprehension and motor execution (Goldenberg, 2014). Despite ongoing controversy over such claims, researchers have previously conducted studies concerning mechanical knowledge of the human body vs. manikins (Goldenberg, 1995; Goldenberg & Hangmann, 1997; Goldenberg & Hangmann, 1998b), tool use in traditional vs. non-traditional ways (Osiurak et al., 2008; 2009; 2013; Spatt et al., 2002), and brain and neural activation for familiar vs. novel/ meaningless imitation tasks (Hermsdorfer et al., 2001; Peigneux et al., 2004).

Beyond cognitive mediation, the findings of mirror neuron studies provide the empirical information to further understand brain processes linked to praxis skills (Buxbaum, Kyle, & Menon, 2005; Goldenberg & Karnath, 2006). In the mirror neuron system, certain identical neural representations are supposedly activated when the action is performed (action production) and when an individual observes the action (action perception) (Lacoboni & Dapretto, 2006; Rizzolatti & Craighero, 2004; Rizzolatti & Luppino, 2001). In addition, other studies have proposed a multi-modal mirror network process, postulating that the same neural mirror circuits activated with auditory stimulus-producing actions are also activated during visual stimulus-producing actions (Galati et al., 2008; Gazzola, Aziz-Zadeh, & Keysers, 2006; Keysers, et al., 2003; Kohler et al., 2002; Bangert et al., 2006; Lahav et al., 2007; Warren et al., 2006).

The preceding overview of the symptoms and mechanisms of apraxia, including an historical background and neuropsychological models, is aimed at providing the foundational information about IMA needed to better understand apraxia's' etiology. In the following section, this study will examine how these symptoms and mechanisms physically and functionally affect patients with IMA. This examination, in turn, may provide further insights on assessing the study participant experience and designing beneficial therapeutic interventions.

Physical and Functional Impacts of Ideomotor Apraxia in Stroke

Stroke can result in devastating motor impairments, including paresis, spasticity, weakness and poor motor coordination (Langhorne, Bernhardt, & Kwakkel, 2011). Among such motor deficits, hemiparesis has been found in roughly 60 to 90% of stroke survivors (Hendricks, Limbeek, Geurts, & Zwarts, 2002; Kwakkel et al., 1999). While most stroke patients eventually regain lower extremity functions such as walking, approximately 30 to 66% of patients demonstrate persistent arm impairments and remain unable to use their arms (Kwakkel et al., 1999). As a result, 75% of post-stroke patients initially exhibit a decreased ability to perform basic activities of daily living (ADLs) (Jorgensen, Nakayama, Raaschou, & Olsen, 1999).

IMA is a common sequela following stroke, particularly in patients with left- hemisphere injury (De Renzi et al., 1980; Donkervoort, Dekker, van den Ende, Stehmann-Saris, & Deelman, 2000). IMA-centered studies have generally estimated that approximately 30% to 54% of patients with left- hemisphere stroke suffer impaired movement attributable to apraxia (Bickerton et al., 2012; Civelek et al., 2015; Donkervoort et al., 2000; Kaya et al., 2006; Zwinkels et al., 2004). Apraxia has also been estimated to affect 6 to 25% of right-hemisphere stroke patients (Bickerton et al., 2012; Civelek et al., 2015; Kaya et al., 2006; Zwinkels et al., 2004). One recent study reported an IMA prevalence rate of 36% in first-time stroke inpatients (Civelek et al., 2015), while another study found that approximately 46% of first-time stroke sufferers demonstrated at least one praxic symptom (Bickerton et al., 2012). Considering the important role that upper extremity (UE) function plays in the performance of meaningful daily tasks, an individual suffering from arm paresis and other stroke-related consequences such as IMA will likely experience significant impacts on functional independence and quality of life.

Spatiotemporal Features of Ideomotor Apraxia

To demonstrate the impact of apraxia on action performance, several studies have used kinematic analyses of movement examining detailed information about limb trajectories alongside accurate measurement of errors. Poizner and his colleagues (1990) first utilized a three-dimensional analysis of the movement errors demonstrated by two apraxia patients. This analysis demonstrated the patients' impairments by controlling for the spatial and temporal aspects of their movement trajectories as compared to healthy normal controls (Poizner et al., 1990). Subsequently, another study by Poizner et al. (1995) assessed the joint coordination deficits that patients displayed when making slicing gestures; such deficiencies appeared in various contexts: both the planning (spatial aspect) of the movement and the process of translating the plan into actual movement with proper joint angle execution. Moreover, the study found that the patients presented with these impairments when actually using tools and objects as well (Poizner et al., 1995).

The larger sample in the study of Haaland et al. (1999) found that 26 patients with left-hemisphere damage exhibited impairments in spatial aspects of movement (e.g., spatial location and hand position) during a simple aiming task, thus demonstrating the deficits in action implementation affecting apraxia patients. Clark et al. (1994) tested the bread-slicing movement task and found that post-left-hemisphere stroke patients suffering from apraxia demonstrated varied, less linear and curved wrist movement trajectories as well as lower wrist velocity. The patients' impaired coupling between the speed and trajectory of hand movements was also compared to healthy control subjects (Clark et al., 1994). Additional data points on coordination and dynamic aspects of movement errors (as evidenced by higher variability and initial direction errors) were compiled in yet another study (Mutha et al., 2010), which assessed patients with IMA performing reaching tasks to visual targets.

Randerath et al. (2010), meanwhile, investigated the single-tool action, specifically, action involving a grasping movement. They found that patients with left-brain damage exhibited non-functional grasping of the tool handle, which was significantly different from the performance of healthy control subjects. Disruptions in grasping (prehension tasks) were also addressed by Laimgruber, Goldenberg, and Hermsdorfer, (2005) who observed that patients with left-brain damage demonstrated prolonged adjustment times before grasping a glass of water and exhibited significantly smaller (or missing) hand apertures during pantomime tasks.

Spatiotemporal errors of arm movement execution have also been observed in patients making meaningless gestures (e.g., arm movements toward the head with a specific final position of the hand around the head) (Hermsdorfer et al., 1996) or tool-use action (e.g., hand-sawing a piece of wood) in different modes such as pantomiming with/without the saw and actual sawing (Hermsdorfer et al., 2006). While a number of abnormalities were identified in such studies, including repeated changes in direction, multiple-peaked velocities, and prolonged adjustment phases during gestures, apraxia patients nevertheless achieved the correct final position or were observed controlling their speed (Hermsdorfer et al., 1996). These findings imply that they deployed their own strategies to achieve the given tasks. Also, such movement errors as expressed during pantomiming of tool use (Hermsdorfer et al. 2006) or simple arm- and hand-aiming tasks (Haaland et al., 1999) had improved when actual object or visual feedback of target location or hand position were provided. However, uncertainty of movement function persisted in patients who had apraxia-related impairments resulting from direct motor coordination impairments or who encountered conceptual problems with planning and execution (Hermsdorfer et al. 2006).

Functional Impact of Ideomotor Apraxia

While researchers have previously addressed various spatiotemporal abnormalities related to the upper extremities in the context of apraxia, other studies have parsed the functional impact of apraxia, particularly in conjunction with post-stroke IMA. The resultant evidence suggests that apraxia has an adverse influence on daily living skills. These studies have mainly investigated the relation between apraxia scores and the measurement of functional dependence, usually relying on self-reporting, researcher-led observations or questionnaires (Bjorneby & Reinvang, 1985; Hanna-Pladdy et al., 2003; Sundet et al., 1988). One study by Sundet et al. (1988) comprised a six-month assessment of independent functioning in basic ADLs for post-stroke patients following their discharge from the hospital. The multiple regression results revealed that apraxia scores (assessed by imitation of gestures) were a significant predictor of questionnaire ratings for ADL dependency, suggesting that IMA likely increases functional dependence (Sundet et al., 1988). In a similar vein, Hanna-Paddy et al. (2003) examined ADL functioning in 10 left-hemisphere stroke patients and an age-matched healthy control group, and found a significant relationship between IMA severity and ADL dependency. The findings suggested that patients with apraxia experienced decreased independence in self-care skills such as grooming, bathing and using the toilet, while functional independence was nonexistent for dressing, feeding or walking (Hanna-Paddy et al., 2003). Bjorneby and Reinvang (1985) investigated apraxia patient dependency in a study involving a group of 120 stroke patients in a rehabilitative setting. The apraxia measurement scores were observed by nurses and compared between two groups: a 'dependent' group, whose members needed caregiver assistance in performing daily living tasks, and an 'independent' group, whose members were independent in ADL functioning. The study concluded that apraxia scores were significant predictors of post-stroke dependency in ADL functioning (Bjorneby & Reinvang, 1985).

In addition to observation ratings and statistical analyses of ADLs, more detailed basic daily tasks were investigated via videorecording to determine whether apraxia impacted correct performance of ADLs. Foundas et al. (1995), for example, followed 10 left-hemisphere apraxia patients' mealtime behaviors by comparing their conduct during lunch to an age-matched neurologically normal control group. Patients with apraxia were less efficient and more disorganized in sequencing movement orders, and made more errors while using tools (i.e., utensils) compared to non-tool performance; such shortcomings could not all be attributed to elementary motor deficits such as hemiparesis (Foundas et al., 1995). Another study by Goldenberg and Hangman (1998a) evaluated the movement and sequential errors made by patients executing ADL tasks (e.g., spreading butter on bread, brushing teeth). Out of 35 left-hemisphere stroke patients suffering concurrently from apraxia and some type of aphasia, only 25.7% were able to complete all ADL tasks without making any errors; meanwhile, 17.1% could not complete a single task. A subsequent study (Goldenberg et al., 2001) tested more complex tasks (e.g., preparing coffee with an automatic drip coffeemaker, changing batteries in a tape recorder). The results of this research found that left-hemisphere stroke patients with apraxia had more difficulty with ADLs than those without apraxia; the latter group, in turn had more difficulty than the healthy controls (Goldenberg et al., 2001).

Weiss and colleagues (2008), meanwhile, deployed videorecordings in a slightly different role in their research study. They examined the difficulties encountered by post-left-hemisphere stroke patients with IMA in sequencing multistep actions by presenting patients with video clips of ADLs (e.g., affixing a stamp on a letter, lighting a candle using matches). The clips included both correct and incorrect ordering of sequences, which the patients then had to detect. IMA patients showed deficits in detecting sequential errors (Weiss et al., 2008).

Other studies have also closely investigated upper extremity difficulties arising in stroke patients as they tackle dressing skills, specifically, putting on a polo shirt (Sunderland et al., 2006; Walker et al., 2004). The videotaped findings showed that patients were able to dress independently if they had preserved the UE ability to use both arms bilaterally due to their habitual routine of dressing skills (Sunderland et al., 2006; Walker et al., 2004). Yet even while eventually completing the tasks, the patients were initially unable to put on their shirts, which suggests that the underlying cognitive problems related to apraxia may hinder the adoption of new strategies, requiring patients to learn a new compensatory method of completing the dressing tasks with one hand (Walker et al., 2004).

Additionally, different dressing errors were reported among patients with differently localized brain damage. Patients with left-hemisphere damage were more likely to demonstrate planning problems (e.g., dressing the non-paretic arm first), while visuospatial and attention deficits (e.g., finding the correct openings for the arm or head) were more frequent among patients with right- hemisphere damage (Sunderland et al., 2006). The results of such studies targeting the ADL of dressing suggest the complexity of the functional challenges confronting patients with apraxia, a disorder that contributes to supplementary compilations. Such patients face exacerbated ADL-related difficulties as compared to patients afflicted only with left-hemisphere damage (Goldenberg, 2001; Sunderland et al., 2006; Sunderland & Shinner, 2007; Walker et al., 2004).

In addition to evidence of reduced independence in ADL skills, recent studies have further shown decreased functional improvement in ADL in the presence of apraxia. These results of disrupted ADL functioning were observed among in-patient populations with post-stroke IMA (Civelek et al., 2015; Unsal-Delialioglu et al., 2008; Wu et al., 2014). Even though left-hemisphere damaged inpatient sufferers of IMA showed some functional gains during rehabilitation, the presence of apraxia impeded their gains, evidenced by the fact that the level of independence in patients with IMA at the time of hospital discharge was either below (Unsal-Delialioglu et al., 2008) or similar to (Wu et al., 2014) the level of patients without apraxia at the time of admission. Thus, patients with IMA had significantly lower functional independence scores as compared to patients without apraxia both at the time of admission and at discharge (Civelek et al., 2015). Such dysfunctions were shown to affect not only patients with left-hemisphere damage, but those with right-hemisphere damage as well (Civelek et al., 2015). Donkervoort et al. (2006) studied 104 left-hemisphere stroke patients with apraxia and found fewer improvements in motor functions and life functioning among patients with more severe apraxia than in those with less severe apraxia during their hospitalized period in rehabilitation centers and nursing homes. Apraxia symptoms also persisted in roughly 88% of the patients at the 20-week mark in the study (Donkervoort et al., 2006). Furthermore, functional skills improved during the in-hospital treatment period, but in many cases patients experienced difficulties in transferring the skills learned at the hospital to their homes and in maintaining the same level of improvement following hospital discharge (Bjorneby & Reinvang, 1985).

As evidenced in the abovementioned studies, the physical and functional challenges presented by the onset of apraxia in the wake of a stroke are real and formidable ones. Yet historically, the literature has expressed that apraxia has few real-world implications, due in part to the belief of spontaneous recovery after injury or of the phenomena of voluntary automatic dissociation; such assumptions have generally impeded further investigation and development of rehabilitative regimens for apraxia (Maher & Ochipa, 1997). However, the more recent findings cited above upend the classical view on apraxia by demonstrating how the disorder exerts adverse influences on patients' independence in daily functioning. An improved understanding of the impact of IMA on physical motor function and functional performance is thus crucial if clinicians are to improve the implementation of intervention and enhance the likelihood of optimal therapeutic outcomes.

Interventions Related to Apraxia

A number of limited studies have investigated treatments aimed at improving apraxia-impaired UE function (Cantagallo et al., 2012; Dovern et al., 2012; Cicerone et al., 2005; Maher & Ochipa, 1997; West et al., 2008). The results of some studies point to the difficulty of directly treating apraxia (Ochipa & Rothi, 2000; Smania et al., 2006), since recovery may not be an ideal therapeutic goal for the treatment process. Accordingly, patients may be encouraged to continue rehabilitation to help themselves adapt to and compensate for lost functionality (Buxbaum et al., 2008; van Heugten, 2001). Despite the general lack of relevant rehabilitation studies, treatment for post-stroke apraxia patients nonetheless plays an essential therapeutic role in many clinical settings. The following section describes intervention regimens for apraxia, including gesture training, strategy training, errorless direct and exploration training, and other varied treatment approaches with single-subject case studies.

Gesture Training

A pair of earlier studies first introduced the use of gesture training as a potential treatment for apraxia (Smania et al., 2006; Smania, Girardi, Domenicali, Lora, & Aglioti, 2000). This treatment focuses on training left-hemisphere stroke patients to perform IMA-related transitive and intransitive gestures. In both of the randomized controlled trial studies cited above, specific transitive/intransitive gesture training was compared to a dose-matched conventional therapy (aphasia treatment). The transitive gesture training consisted of three phases: first, the patients were presented with actual objects (common tools) and asked to demonstrate their appropriate use. Patients were then shown pictures of a portion of the gesture usage in appropriate context and asked to imitate the object use as seen in the picture. Finally, they were shown pictures of a common object and asked to pantomime the use of it. The intransitive gesture also comprised three phases: patients were first presented with two pictures – one illustrating a specific context and the other depicting a symbolic gesture matched to the context – and were then asked to imitate the gesture. Next, they were shown only a context picture and asked to demonstrate the appropriate gesture. Finally, they were presented with a related but new context picture and asked to demonstrate the appropriate gesture (Smania et al., 2006, 2000).

In the earlier study by Smania and colleagues (2000), the results of 35 fifty-minute sessions involving 13 IMA patients (six for the experimental group and seven for the control group) showed significantly improved performance in gesture comprehension and related apraxia tests assessing, among others, error reduction in real object use and imitation of intransitive gestures; the control group did not exhibit any significant change in performance. The second study (Smania et al., 2006) included a larger sample of 33 patients (18 for the experimental group and 15 for the control group), conducting 30 sessions to investigate clinical application. In this study, patients undergoing gesture training demonstrated not only improved praxic function, but also functional independence according to caregiver evaluations of ADL independence. Furthermore, the positive training effect lasted for 2 months after the final session (Smania et al., 2006). Though the studies failed to provide additional details, their authors assumed that the positive effect of gesture training targeting specifically trained tasks could be transferred to other tasks in different contextual situations (Smania et al., 2006, 2000).

Strategy Training

Other studies have developed strategy training in order to teach patients strategies to compensate for the presence of apraxic impairment in their daily lives (Donkervoort, Dekker, Stehmann-Saris, Deelman, 2001; Guesgens, van Heugten, Cooijmans, Jolles, & van den Heuvel, 2007; Guesgens et al., 2006; van Heugten, Dekker, Deelman, Stehmann-Saris, & Kinebanian, 2000; van Heugten et al., 1998). In contrast to gesture training, which seeks to maximize the recovery or return of functionality by correcting apraxic deficits (e.g., use of gestures), the strategy training approach, as a substitutive treatment, is designed to help patients effectively exploit residual skills by teaching them new ways to minimize the extent to which problems impinge on daily activities (Maher & Ochipa, 1997). The strategy training featured in such studies (Donkervoort, et al., 2001; Guesgens et al., 2007, 2006; van Heugten, et al., 2000, 1998) focuses on the use of internal (e.g., self-verbalization) and external (e.g., use of visual cues such as pictures, list of action sequence, physical assistance) modalities to create compensatory strategies aimed at maximizing functional independence – all while assuming that apraxia is a persistent impairment.

In the abovementioned studies on strategy training, three to five targeted ADLs were conceptualized and practiced so as to comprise three successive stages: first, the patients selected the proper plan of action and the correct objects (initiation); the plan was then adequately performed (execution); and the results were finally evaluated and corrected as necessary (control) (Donkervoort et al, 2001; Guesgens et al., 2007, 2006; van Heugten et al., 1998). The instruction (verbal), assistance (verbal or physical), and feedback were presented within a specific protocol, while the duration, specific details, and intensity of treatment varied among patients, depending upon each individual's functional level and degree of impairment (Donkervoort et al, 2001; Guesgens et al., 2007, 2006; van Heugten et al., 1998).

The initial study in this research stream included 33 individuals with apraxia secondary to left-hemisphere stroke (van Heugten et al., 1998). In this exploratory study, the patients showed significant improvements in ADLs after 12 weeks (three to five 30- minute sessions per week) of ADL functioning strategy training despite persistent apraxia. Positive training effects measured by ADL observation scores were also reported under similar research conditions in a study comparing strategy training efficacy against a control group of patients without apraxia who underwent no treatment (van Heugten et al., 2000). Donkervoort et al. (2001) examined the efficacy of similar strategy training for 113 left-hemisphere stroke patients with apraxia in a randomized controlled trial. Eight weeks of strategy training resulted in positive outcomes in ADL functioning (measured by both the Barthel Index and ADL observations scores), with the experimental group exhibiting significantly greater grains than those of the control patients, who received only conventional occupational therapy. However, such improvements did not persist 5 months after the onset of the study (Donkervoort et al., 2001). Meanwhile, researchers in a subsequent study suggested that strategy training could potentially be generalized to apply to other therapeutic areas, demonstrating that the positive treatment effects of trained tasks could be transferred to non-trained tasks (Guesgens et al., 2006). Furthermore, a more recent study examining a strategy training series reported additional significant improvements in ADL performance at the 3-month follow-up after the initial session, a finding that supports the persistence of strategy training's therapeutic effects (Guesgens et al., 2007).

Errorless Direct Training and Exploration Training

Errorless direct training and exploration training comprise two other therapeutic approaches for the treatment of apraxia. Originally explored in a series of studies conducted by Goldenberg and his colleagues (Goldenberg & Hangman, 1998a; Goldenberg et al., 2001), the first of the two methods, direct training, aims at restoring patient independence in ADL performance by minimizing errors in action completion. This approach of encouraging patients to complete an entire activity without committing errors involves the therapist's physical assistance and simultaneous modeling of a specific ADL, followed by the patient's imitating of the ADL performance. In contrast to direct training, explorative training does not include the actual execution of targeted ADL actions; rather, it aims to teach patients to recognize the functional significance and critical details of actions and to infer the function of an object from the function's structure -- a potentially critical step in mechanical problem solving (Goldenberg & Hangman, 1998a, 1998b; Goldenberg et al., 2001).

In a Goldenberg and Hangman study (1998a), these two approaches were combined to treat 15 left-hemisphere stroke patients with subsequent aphasia and apraxia who encountered difficulty in performing ADLs such as eating, dressing, or grooming. Results of this combined direct and exploration training study confirmed significant improvements in trained ADLs due to a decrease in fatal errors. Treatment efficacy lasted for six months, but only for those patients who continued to practice the ADL tasks at home (Goldenberg & Hangman, 1998a). In a follow-up study (Goldenberg et al., 2001), the effects of direct training and exploration training were directly compared after six 1-hour sessions conducted over the course of two weeks. While the direct training was shown to result in positive (reduced errors) and relatively long-lasting effects three months post-study, the explorative training demonstrated no effect on ADL performance (Goldenberg et al., 2001). In spite of the promising positive gains, in neither of the two studies did the training effects generalize to impact other untrained tasks (Goldenberg & Hangman, 1998a; Goldenberg et al., 2001).

Case Studies: Incorporating Various Treatment Interventions

Several single-case studies also contain promising initial findings for the rehabilitative efforts aimed at patients with apraxia. For example, Maher, Rothi, and Greenwald (1991) used multiple cues, including tools, objects, visual models and feedback, to treat gestures for an IMA patient who preserved gesture recognition. During the study's therapy sessions, errors were corrected with various cues, which were systemically withdrawn upon improved performance. Study results confirmed improvements in the patient's gesture production (Maher & Ochipa, 1997; Maher et al., 1991).

In a subsequent experiment using the multiple-cue approach, Ochipa, Maher, and Rothi (1995) focused on the treatment of specific error types. To reduce the errors, treatment consisted of training for external and internal configurations such as orienting the hand, positioning the hand and fingers in relation to objects, etc. Two chronic IMA patients achieved considerable and lasting improvements (two weeks post-study) after participating in the training, but the treatment effects were specific to treated items and did not transfer to untreated gestures or error types (Maher & Ochipa, 1997; Ochipa et al., 1995).

Pilgrim and Humphreys (1994) found that focusing on task analysis of movement articulation through physical and verbal assistance – a process known as the conductive education approach – yielded improved patient performance; however, there was no generalization effect for untreated objects. Meanwhile, Butler (2000) designed a sensory stimulation protocol including various tactile and kinesthetic stimulations (e.g., deep pressure, proprioception, sharp, soft or self-touching) alongside verbal and visual modeling for IMA-related rehabilitation following a brain injury. While mixed results were reported with a partially positive increase in motor performance, the study produced only limited evidence that the protocol elicited possible practice effects and natural motor recovery (Butler, 2000).

A more recent case study involving electrical stimulation or transcranial direct current stimulation of the left posterior parietal cortex in six IMA patients resulted in improved timing for performing skilled movement (gestures) and planning (Bolognini et al., 2015). Another work by Wu, Radel, and Hanna-Pladdy (2011) investigated the efficacy of a new treatment approach combining physical and mental practices to improve the ADL skills of an IMA patient following left-hemisphere stroke. Eighteen 1-hour sessions focused on two daily tasks, with 30 minutes of physical activity practice followed by 30 minutes of guided mental imagery practice corresponding to the physical activity. Despite the persistent IMA of the subjects, the training resulted in considerable functional improvements and bolstered the patients' self-perception of their performance. Additionally, the improvements persisted for one month after treatment (Wu et al., 2011).

The case studies described above use various treatment strategies to demonstrate the potential promising effects of treatment for individuals with apraxia, with a particular emphasis on improving functional performance in everyday life. As outlined in this literature review, current common treatment strategies currently tend to focus on teaching compensatory techniques, even when patients present with apraxia (Buxbaum et al., 2008). However, despite somewhat limited and inconsistent empirical evidence on the efficacy of rehabilitative treatments for patients with apraxia, researchers strongly agree that such patients should nevertheless continue to receive rehabilitative therapy (Buxbaum et al., 2008; Cantagallo et al., 2012; Cicerone et al., 2005; Dovern et al., 2012; van Heugten, 2001; West et al., 2008). Consequently, there is a pressing need to accrue more evidence validating current treatment approaches as well as spurring the development of new and innovative treatments, including regimens such as music therapy.

Music and Motor Rehabilitation

Rhythmic and Motor Control

One relatively new and promising approach to stroke rehabilitation is the auditory rhythmic model of motor entrainment, which has been shown to improve motor control in post-stroke patients (Thaut & McIntosh, 2014). Rhythm, one of the basic musical elements, is a temporal organizer that entrains motor responses by stabilizing and steadying movement. Earlier research has documented the existence of auditory-sensorimotor pathways (via supraspinal influences) through which auditory input, specifically rhythm, can provide priming (or readiness) and timing effects on muscle activation (Paltsev & Elner, 1967; Rossignal & Melvill Jones, 1976). Rhythmic entrainment can improve the quality of movement by priming the motor system to be ready to move, facilitating anticipation, and effectuating adaptive changes in motor planning and execution (Thaut, 2013). Thus, rhythm provides continuous movement information throughout the duration of the movement so that the targeted action can be fixed and modulated at any moment. Specifically, UE movements are considered more discrete, non-rhythmic, and complex than those of the lower extremities. Rhythmic cues via entrainment thus not only provide a timing structure but also influence spatial-positional control of movement (e.g., appropriate velocity, acceleration) for the duration of the entrainment, facilitating optimal motor planning and execution (Thaut, 2013, Thaut, McIntosh, & Hoemberg, 2015).

Neuroimaging research has demonstrated that UE-focused music training increases activation of the brain's motor-related areas through neuroplasticity. The areas involved with musical motor training are the same brain regions linked with other motor tasks, including the motor, premotor and supplementary motor areas, the cerebellum and basal ganglia. These areas are also involved in auditory, somatosensory, temporal, emotional and memory associations (Altenmuller et al., 2009; Jamali et al., 2014; Meister et al. 2004; Tramo, 2001). Auditory-motor plasticity has been observed in healthy individuals (Konoike et al., 2012; Tecchio, Salustri, Thaut, Pasqualetti, & Rossini, 2000; Tierney & Kraus, 2013), including in musicians, non-musicians with no formal musical training (Bangert & Altenmuller, 2003; Bangert et al., 2006;

Lahav et al., 2007), and stroke patients (Altenmuller et al., 2009; Fujioka et al., 2012; Ripolles et al., 2016; Rodriquez-Fornells et al., 2012; Rojo et al., 2011).

The positive effects of rhythm on UE functions buttress the argument for utilizing music in motor rehabilitation. Researchers have investigated the immediate effects of rhythmic cueing on UE movement in healthy subjects by increasing muscle activation and coactivation (Thaut, Schleiffers, & Davis, 1991), and in post-stroke patients by increasing the range of elbow motion, movement timing, and smoothness of reaching trajectories (Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002). In subsequent research, repetitive rhythmic arm training was also shown to be effective in stroke rehabilitation (Malcolm, Massie, & Thaut, 2009); in that study, a rhythmic reaching protocol increased individual's contributions of shoulder flexion and trunk rotation and significantly decreased compensatory trunk movement such as trunk flexion and shoulder abduction. In contrast, common compensatory movement patterns were seen to persist in a study utilizing Constraint-Induced Movement Therapy (CIMT), which has traditionally been considered as one of the most effective evidence-based UE treatments (Massie, Malcolm, Greene, & Thaut, 2009). Ultimately, such improved arm functions were functionally generalized into ADL skills with the help of rhythmic training (Malcolm et al., 2009).

Numerous studies have documented bilateral arm training with Rhythmic Auditory Cueing (BATRAC), an emerging approach that has spawned positive outcomes in patients with post-stoke UE paresis (Luft et al., 2004; McCombe Waller, Harris-Love, Liu, & Whitall, 2006; McCombe Waller & Whitall, 2008; Whitall, McCombe Waller, Silver, & Macko, 2000). Bilateral UE training is based on the premise that non-paretic UE movement can support movement of the paretic arm through simultaneous performance, and is considered as effective as unilateral training regimens such as CIMT (van Delden, Peper, Beek, & Kwakkel, 2012). The results of several studies have shown that when exercising with rhythmic cueing, patients demonstrated temporal coupling in both arms when moving them simultaneously, despite hemiparesis (McCombe Waller et al., 2006). These patients marked greater improvements in terms of faster, increased movement control and smoothness of hand functions (increased peak acceleration, smoother hand paths) than patients who performed dose-matched therapeutic exercise without musical cues (McCombe Waller, Liu, & Whitall, 2008). Furthermore, other research has shown that such benefits also transfer to functional improvements in the patients' gross motor functional measures (Senesac, Davis, & Richards, 2011). The BARTAC studies hint at the importance of spatial control and temporal considerations as factors leading to improved arm-reaching performance (McCombe Waller et al., 2008).

Therapeutic Instrumental Music Performance for Improving Upper Extremity Function in Stroke Patients

Therapeutic Instrumental Music Performance (TIMP) is a therapeutic intervention in which individuals play musical instruments for therapeutic purposes. By incorporating such musical instruments (e.g., various rhythmic percussion instruments or keyboard), TIMP can facilitate functional movements and ultimately improve gross or fine motor skills such as strength, range of motion, dexterity, endurance, and motor control (Elliott, 1982; Thaut, 2005). While music, as a sensory cue, can be used to structure movements in time and space and regulate movement patterns, TIMP allows the therapist to design the spatial positioning and arrangement of the musical instruments so as to facilitate the desired trajectory and position of movements (Mertel, 2014). Backed by its ongoing utilization in rehabilitative regimens, TIMP is increasingly regarded as a promising therapeutic tool for improving post-stroke patients' UE motor functions (Magee, Clark, Tamplin, & Bradt, 2017; Moumdjian, Sarkamo, Leone, Leman, & Keys, 2017).

In an investigation of TIMP's emerging benefits, an earlier pilot study involving chronic stroke patients found that six 35-minute TIMP training sessions using MIDI drum playing spurred functional improvements of the wrist and hand and observable improvements in speed, force, and motor control of the upper extremities (Yoo, 2009). In light of these promising findings on TIMP's potential to help stroke survivors regain functional independence, a follow-up study redesigned the experiment to target daily living tasks such as carrying a cup, typing on a keyboard, or using a vacuum while various rhythmic instruments were played. The results of this exploratory study showed that all three chronic stroke patients exhibited observable increases in UE motor and functional skills as well as in their self-perceptions of performance after 12 one-hour TIMP training sessions spread over a 4-week period (Yoo, 2015).

Music intervention known as Music-Supported Training (MST) was found to be effective in studies of post-stroke rehabilitation of motor function (Altenmuller et al., 2009; Schneider et al., 2010, 2007). In these studies, stroke patients engaged in MST exercises that consisted of fifteen to twenty 30-minute training sessions with MIDI piano and electronic drum pads (Altenmuller et al., 2009; Grau-Sanchez et al., 2013; Schneider et al., 2010, 2007). The study results demonstrated that when equal amounts of time and intensity were expended on each therapeutic regimen, MST led to more significant motor improvements in speed, precision, smoothness of movement and motor control than those produced by Constraint-Induced Movement Therapy (CIMT) (Schneider et al., 2010) or other conventional therapies (Altenmuller et al., 2009; Schneider et al., 2007), or in the absence of a training control condition (Grau-Sanchez et al., 2013). Besides movement analysis, all of the abovementioned studies observed significant functional improvements for patients' ADL skills, which suggests that MST regimens may have general applications outside of therapy settings to improve functional independence (Altenmuller et al., 2009; Grau-Sanchez et al., 2013; Schneider et al., 2010, 2007). In addition to these functional improvements, the findings also provided evidence of neural reorganization, including increased activation of motor and auditory regions, excitement of the motor cortex (Grau-Sanchez et al., 2013; Ripolles et al., 2016), incorporation of auditory cortices in motor circuits (auditory-motor coupling), (Rodriquez-Fornells et al., 2012; Rojo et al., 2011), corticospinal integrity (Amengual et al., 2013), event-related desynchronization and cortico-cortical coherence (Altenmuller et al., 2009).

Furthermore, the benefits of TIMP have inspired one group of researchers to develop a protocol for use at patients' homes. The home-based intervention protocol for 12 individual sessions employs various rhythmic instruments (e.g., bongos, cymbals) and Garage Band software specially designed for chronic post-stroke patients (Street, Magee, Odell-Miller, Bateman, & Fachner, 2015). Results thus far in an ongoing small-sample feasibility pilot study have already noted positive UE functional outcomes in arm functions and finger dexterity, illustrating the potential for stroke patients to obtain therapeutic benefits at the community rehabilitation stage (Street et al., 2018).

Researchers have also used keyboard training to investigate TIMP's retention effect in stroke survivors. In the relevant studies, nine 1-hour-piano training sessions consisted of structured finger movement practice that involved consecutive and non-consecutive finger playing and two-finger simultaneous playing on the keyboard (Villeneuve, & Lamontagne, 2013; Villeneuve et al., 2014). The three-week piano training period also implemented home practice and ultimately accounted for functional gains in fine motor skills (Villeneuve, & Lamontagne, 2013; Villeneuve et al., 2014). Such improvements employing piano playing also extended to patients who played in group settings (playing in turn or playing synchronously), a socially engaged activity that resulted in improvements in both mood and fine motor functions (van Vugt et al., 2014). Significant improvements in dexterity and functional use of the upper extremities persisted for three months after the initial musical training session (Villeneuve, & Lamontagne, 2013; Villeneuve et al., 2014).

Moreover, these instances of sustainable progress were seen in patients with mild to moderate UE functioning problems (Villeneuve, & Lamontagne, 2013) as well as in patients facing more difficult challenges (Villeneuve et al., 2014). These findings suggest that the regimen could potentially help a wide spectrum of post-stroke patients, whose functional disorders can range from mild to debilitating (Villeneuve et al., 2014; Yoo, 2015). Study results from Raghavan and colleagues (2016) also demonstrated promising rehabilitative potential for individuals who may need more attentive care. After collaborating with an occupational therapist, 12 instrument-playing music interventions, chronic stroke survivors exhibited significant improvements in UE and sensory functions, perceptions of well-being, and emotional engagement; patients also voiced new positive attitudes toward their impairment. Further, low-functioning individuals demonstrated more profound UE improvement such as increased range of wrist motion than their higher functioning study peers (Raghavan et al., 2016). These results illustrate the importance of maintaining therapeutic efforts for all functional capacities in the wake of a stroke.

The findings of the abovementioned studies strongly suggest that therapeutic musical instrument playing intervention can be successfully applied to treat paresis in post-stroke patients.

These promising results further buttress the argument for utilizing such regimens to improve rehabilitation efforts for post-stroke comorbid disorder such as apraxia.

Music in the Context of Ideomotor Apraxia in Stroke

Music activity engages the motor and multisensory networks in the brain, facilitating neural activation, change or adaptation (Altenmuller & Schlaug, 2013, Thaut, 2005). Numerous studies have argued that the widely distributed brain regions most commonly associated with apraxia appear to be involved in rhythmic perception and production processes, including the left inferior parietal lobe (IPL), supplementary motor area (SMA), dosal premotor cortex (dPMC), prefrontal areas, inferior frontal cortex (including Broca's area) and superior temporal gyrus (including Wernike's area), as well as the primary motor and somatic sensory areas and premotor cortex (Bangert et al., 2006; Bengtsson et al., 2009; Chen, Penhune, & Zatorre, 2008; Fujioka et al., 2012; Harrington et al., 1998; Jamali et al., 2014; Konoike et al., 2012; Lahav et al., 2007; Thaut, 2003; Thaut, Demartin, & Sanes, 2008; Thaut et al., 2009; Tierney & Kraus, 2013).

While recent research has linked high auditory-motor plasticity with music playing training (Bangert & Altenmuller, 2003; Bangert et al., 2006; Jamali et al., 2014; Ripolles et al., 2016), non-active musical activities have also been shown to simulate brain areas linked to apraxia. Playing on a soundless keyboard (playing without sound), listening to music that was previously played (absence of movement) (Bangert & Altenmuller, 2003; Bangert et al., 2006; Bengtsson et al., 2009; Lahav et al., 2007) or even simply imagining the music (Meister et al. 2004; Schaefer, Morcom, Roberts, & Overy, 2014) induced brain activation of the bilateral temporal and frontoparietal areas (including premotor and BA 40), the pre-supplementary motor area (Bangert et al., 2006; Meister et al., 2004; Schaefer et al., 2014), and the left opercular part of the inferior frontal gyrus, including involvement of the mirror neuron (Lahav et al., 2007).

In addition to affecting cortical areas, musical training may also prompt significant changes in white matter tracts, another brain area associated with apraxia. Studies have identified the existence of structural differences in brain development between individuals with and without musical training. For example, musicians (including both singers and players of musical instruments) were shown to have greater tract volume of the actuate fasciculus (Halwani, Loui, Ruber, & Schlaug, 2011) and a larger corpus callosum (Hyde et al., 2009) as compared to non-musicians. Moreover, a number of studies have provided evidence of widely distributed fiber connections in auditory-motor interaction involving the spinal cord, brainstem, cerebellum, basal ganglia, subcortical and cortical levels (Felix II, Fridberger, Leijon, Berrebi, & Magnusson, 2011; Fujioka et al., 2012; Seger et al., 2013; Thaut, 2003; Thaut et al., 2009), areas that may be associated with apraxia as well.

The left parietal lobe is known to be involved in preparing, switching or redirecting movements (Rushworth et al., 2003, 2001) and predicting incoming actions (Fontana et al., 2012). Despite preserving their movement representation (also known as a movement formulae or motor engram), individuals with IMA, who are typically present with left parietal cortex lesions, often experience difficulty in executing the representation of a movement action (Heilman, et al., 1982; Liepmann, 1920; Roy & Square, 1985). The disruption of the internal models (e.g., representation of movement action) of the planning action hinders the prediction of the movement's consequences as well as the process of completing the targeted motor action (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005).

As mentioned earlier, the rhythmic entrainment mechanism established the principal role allotted to auditory rhythm in UE motor rehabilitation for stroke survivors (Malcolm et al., 2009; Thaut, 2013). Auditory stimulation can prime motor networks to be ready to move, while entrainment exerts an influence over the entire duration of the movement time, allowing for an entire movement to be recalibrated and corrected within a temporal structure (Thaut, 2015). In addition, musical motor performance utilizes feedforward and feedback mechanisms to integrate auditory and motor information. The act of playing instruments allows the desired motor outcome to be influenced and primed through the auditory system, providing foreknowledge of movement (feedforward); the created action can then be evaluated for appropriateness and possible correction according to the sound produced (feedback) (Altenmuller et al., 2009; Rojo et al., 2011). Based on music's role in facilitating movement patterns as external rhythmic cues and on music's feedback/feedforward regulations, the temporal ordering of the auditory patterns that patients play on the instruments and the sequentially patterned cues in the music may help IMA sufferers improve their anticipatory planning and executing (Thaut & McIntosh, 2014).

TIMP musically optimizes targeted movement control and stability. In the course of practicing arm movements with the help of TIMP, targeted functional movements can be easily facilitated through the use of temporal (rhythmic), spatial (melodic), and force (dynamic-harmonic) cues, a technique known as Patterned Sensory Enhancement (PSE). PSE enables temporal, spatial, and force components of kinematic movement patterns to be represented and facilitated with musical components (Thaut, 2005). Accordingly, a PSE mechanism can be frequently incorporated into TIMP exercises in sessions. While patients with IMA commonly commit errors involving spatial and temporal aspects of movement (Buxbaum et al., 2014; Leiguarda, 2001; Manuel et al., 2012; Poizner et al., 1995; Rothi et al., 1991), musical cues utilizing rhythm, tempo, pitch, melody, harmony, dynamic elements, etc., can provide extensive spatial and temporal information on targeted movements and facilitate functional movements through music playing. In addition, the playing of musical instruments allows for multisensory facilitations, including tactile, visual and auditory feedback. Thus, for patients who present with difficulties in auditory or visual functions, TIMP can potentially enhance their less impaired sensory modalities in order to allow them to successfully perform the targeted motor actions.

Moreover, music training may produce encouraging results in patients with IMA who profess to typically depend on external cues for executions of action (Haaland et al., 1999). A study by Ramnani and Passinghan (2001) demonstrated the effects of rhythm learning in a case where healthy individuals came to depend on internal rather than external timing cues after music practice sessions. Similar results of increased dependency on endogenous strategies after music training appeared in a post-stroke IMA patient who had suffered left-hemisphere damage (Bernardi et al., 2009). As suggested by these promising results, music training may eventually effectuate positive outcomes in IMA patients by enhancing the structuring of movement and by regulating self-motor control.

Ultimately, the patient's own motivation plays a critical role in determining whether he or she actively engages in rehabilitation efforts. Music activity is closely linked to motivation and emotion, as supported by studies of cortical activation in both animals (Buonomano & Merzenich, 1998) and humans (Sarkamo & Soto, 2012; Sarkamo et al., 2008). For example, musical experiences can provide intense pleasure through peak emotional arousal or anticipation of a reward, emotional states that involve dopamine release in the striatum (Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). A number of studies have documented the use of music in motor function neurorheabilitation in order to enhance patients' mood, participation and social interaction (Jeong & Kim, 2007; Magee & Davidson, 2002; Nayak, Wheeler, Shiflette, & Agostinelli, 2000; Sarkamo et al., 2008). Notably, after undergoing an intervention with musical instruments playing that focused on their UE functions, stroke patients demonstrated improved mood and social/emotional engagement (van Vugt et al., 2014), new feelings of mastery over their impaired UE functions (Raghavan et al., 2016), and increased motivation and adherence to the rehabilitation program (Street et al., 2018). In addition, a similar study has argued that the motivation factor may largely account for why patients benefit more from the music-supported therapy than from auditory feedback (van Vugt et al., 2016).

Few studies have explored the effects of music on individuals with post-stroke IMA. Basso and Capitani (1985) described the intact musical ability of a patient with left-hemisphere stroke suffering from severe IMA and global aphasia. In this case study of a 67-year old former conductor, the patient exhibited dissociations between praxic, verbal and musical functions, presenting persistent, disrupted IMA and aphasia. However, his musical abilities, such as playing the piano and conducting, were largely spared in the wake of the stroke. These intact musical functions included playing the piano for both overlearned movement patterns (e.g., scales) and simple unfamiliar music (Basso & Capitani, 1985). Basso and Capitani (1985) proposed that the undamaged functions of the right hemisphere could reach the damaged left hemisphere by facilitating programming movements in a direct or indirect way, since brain plasticity of the right hemisphere is essential in IMA rehabilitation (Wheaton & Hallett, 2007).

In a similar research stream concerning the therapeutic possibilities of rhythm, Bernardi and his colleagues (2009) investigated the immediate response to rhythmic cuing for gesture-related arm and hand movements in a stroke patient with IMA. During the music training, the left-brain damaged IMA patient practiced complex novel motor sequences (a mixture of three simple gestures) lasting for approximately 15 minutes, both with and without a metronome-like rhythmic cue. The results of four training sessions demonstrated significant improvements in movement accuracy when rhythmic cueing was used, as evidenced by the increased number of correct limb position and trajectories. Furthermore, the data suggested increased self-triggered internal regulation and direction for motor control after the training period (Bernardi et al., 2009). Such results highlighting the immediate effects induced by rhythm comprise a robust evidentiary foundation for the argument that music could be used as a therapeutic stimulus for patients with IMA.

Summary of the Literature and Purpose Statement

Ideomoto apraxia (IMA) is one of the most common sequelae observed in post-stroke patients (Petreska et al., 2007; Wheaton & Hallett, 2007). IMA is a disorder affecting learned skilled movement and is not linked to common stroke-related movement impairments such as elementary motor or sensory deficits or to impaired language comprehension (De Renzi, 1989; Heilman & Rothi, 2003). In line with Liepmann (1920)'s original concept of IMA (i.e., left-hemisphere dominance), a number of ongoing brain studies have found that the disorder may affect diverse areas of the brain, including the parietal area, specifically, the inferior parietal lobe (IPL), and superior parietal lobe (SPL), the frontal and premotor areas, including the supplementary motor area (SMA), the larger context of the distributed fronto-parietal network (middle frontal gyrus and interaparietal sulcus), and the inferior frontal gyrus, including Broca's area, as well as subcortical white matter tracts (Alexander et al., 1992; Bienkiewicz et al., 2014; Bolognini et al., 2015; Buxbaum et al., 2003; Goldenberg, 2009; Haaland et al., 1999, 2000; Halasband et al., 2001; Leiguarda & Marsden, 2000; Randerath et al., 2010; Rushworth et al., 2003).

While researchers today are still parsing the true nature of apraxia, IMA was originally defined as the manifestation of difficulty in accurately executing a particular physical action despite the action's intact spatio-temporal image (Goldenberg, 2003). Indeed, patients with IMA often experience spatial and temporal movement errors (Haaland et al., 1999; Hermsdorfer et al., 2006; Mutha et al., 2010; Poizner et al., 1995); difficulties with daily life functioning (Bjorneby & Reinvang, 1985; Foundas et al., 1995; Goldenberg et al., 2001; Hanna-Pladdy et al., 2003; Sunderland et al., 2006; Weiss et al., 2008); and less functional improvement with rehabilitation (Civelek et al., 2015; Donkervoort et al., 2006; Unsal-Delialioglu et al., 2008; Wu et al., 2014). The presence of any of these drawbacks would likely significantly impact its sufferers' functional independence and quality of life.

The codification of a rehabilitation regimen for IMA sufferers is still in its infancy. This may be partly due to traditional attitudes (e.g., patients can spontaneously recover from IMA) (Basso, Capitani, Della Sala, Laiacona, & Spinnler, 1987) or voluntary-automatic dissociation (e.g., patients perform better at daily living tasks in natural contexts/settings) (De Renzi et al., 1982; Leiguarda & Marsden, 2000; Petreska et al., 2007); either instance which may lead therapists to neglect proper treatment approaches. Traditional rehabilitation methods for IMA include treating apraxia's impairments directly (e.g., gesture training) (Smania et al., 2006, 2000), practicing daily living tasks as a compensatory strategy (e.g., strategy training) (Donkervoort et al., 2001; Guesgens et al., 2007; van Heugten et al., 1998), employing errorless direct training and exploration training (Goldenberg & Hangman, 1998a; Goldenberg et al., 2001), as well as incorporating various treatment interventions (Wu et al., 2011). Yet despite this variety of therapeutic techniques and training regimens, the empirical evidence supporting their efficacy remains limited and inconsistent (Buxbaum et al., 2008; Cantagallo et al., 2012; Cicerone et al., 2005; Dovern et al., 2012; van Heugten, 2001; West et al., 2008). This lack of evidence highlights the need to spur on the development of new, innovative treatments in support of motor facilitation, which may include the therapeutic use of music.

Therapeutic Instruments Music Performance (TIMP) is a research-based therapeutic intervention that involves patients playing of musical instruments to facilitate functional movement patterns. A number of studies have shown that TIMP is effective in improving gross and fine motor functions as well as daily living skills (Altenmuller et al., 2009; Raghavan et al., 2016; Schneider et al., 2010, 2007; Tong et al., 2015; van Vugt et al., 2014; Villeneuve et al., 2014). Such TIMP-derived positive functional improvements are also accompanied by evidence of neuroplasticity changes in the auditory-sensorimotor connections in stroke patients (Altenmuller, et al., 2009; Fujioka et al., 2012; Grau-Sanchez et al., 2013; Jamali et al., 2014; Ripolles et al., 2016; Rodriquez-Fornells et al., 2012; Rojo et al., 2011). What remains to be investigated is whether TIMP can improve UE functions in patients presenting with comorbid post-stroke disorders. Through its integration of motor learning principles and feedback/feedforward regulation, TIMP can be utilized to generate the anticipation and priming of motor networks, which in turn can facilitate in the planning and execution of the targeted action (Thaut & McIntosh, 2014). In addition, the music motor performance, with its positive emotional experience of music-making, motivates patients to be engaged in the activity and to repeat the targeted functional movements (Raghavan et al., 2016; van Vugt et al., 2014), which in turn increases adherence to the therapy program (Street et al, 2018). Accordingly, patients may benefit from purposefully designed musical exercises that utilize multidirectional musical cues in time and space in an efficient and repetitive way. Indeed, several studies involving stroke patients have attested to TIMP's therapeutic potential, as evidenced by improved UE functions observable across a wide functional spectrum of patients, including those with relatively more severe functional impairments (Raghavan et al., 2016; Villeneuve et al., 2014; Yoo, 2015). Considering the plasticity of auditory-motor connections and the rationale for the therapeutic use of music, TIMP constitutes a promising rehabilitative regimen that should be investigated further in patients suffering from stroke-induced paresis and concurrent IMA.

In spite of the prevalent view of IMA as a negative post-stroke predictor (Unsal-Delialioglu et al., 2008, Wu et al., 2014) and its impact on motor performance and daily functioning (Bienkiewicz, et al., 2014; Hann-Pladdy et al., 2003; Sunderland & Shinner, 2007), the literature regarding rehabilitative approaches to IMA is, again, very limited. More specifically, the potential benefits of TIMP intervention have been only narrowly investigated in stroke rehabilitation settings, with less consideration given to stroke-related comorbid disorders. Indeed, earlier entries in the literature have identified the need for additional clinical investigation involving IMA patients, and have instigated the development of efficient treatment protocols aimed at increasing the quality of life for post-stroke IMA patients (Cicerone et al., 2005; Dovern, et al., 2012; West et al., 2008).

The primary focus of this study was to examine the therapeutic potential of TIMP intervention for stroke patients who present with concurrent paresis and IMA. More specifically, the overriding research question that it sought to answer was − Did the TIMP intervention increase upper extremity motor function in patients with post-stroke IMA? In order to assess the persistence of IMA in patients, the study also examined whether individuals with post-stroke IMA exhibited changes in their IMA conditions following the TIMP intervention.

CHAPTER 3

METHOD

Participants

Inclusion Criteria

Patients who met all of the following inclusion criteria were eligible to participate in this study: 1) occurrence of left-hemisphere stroke >6 months prior to study enrollment; 2) ability to demonstrate $\geq 10°$ active wrist extension and $\geq 30°$ shoulder flexion on the more affected side; 3) presence of apraxia confirmed through the apraxia screen of TULIA (AST), as indicated by a total cutoff score of <9 (Vanbellingen et al., 2011); 4) verbal comprehension to follow simple questions, as indicated by a score of $\geq 75\%$ on the Western Aphasia Battery (WAB)'s Auditory Verbal Comprehension Test (yes/no question portion only) (Kertesz, 1982); and 5) ≥ 18 years of age. Exclusion criteria included: 1) excessive pain in the more affected side as defined by a score of ≥ 4 on a 10-point visual analog scale; 2) history of bilateral stroke, other concurrent neurologic disorders or unstable medical condition; 3) severe aphasia; and 4) concurrent participation in any other UE therapy program.

Recruitment Process and Informed Consent

This study was approved by Institutional Review Board of the University of Kansas Medical Center (KUMC) and the American Stroke Foundation (ASF) located in the suburbs of a large metropolitan area in the Midwestern United States. Once their approvals were obtained, potential participants were recruited from both an ongoing KUMC research project (KUMC IRB #study00000842) and the ASF where the current research was conducted. Potential participants from a pre-existing study (KUMC IRB #study00000842) had already consented to future study and subsequently met the eligibility criteria for the current study. The primary investigator of the pre-existing study screened the potential participants and notified each of them about the current study (Appendix A). After the potential participants consented to releasing their contact information, the interventionist-researcher of the current study contacted them by phone and provided an explanation of the study and confirmed their interest in participating (See Appendix A for phone and email script and recruitment flyer).

Participants were also recruited in person (Appendix A) as well as through promotional material (Appendix A) distributed at the ASF. During these recruitment/in-person interactions, the researcher introduced herself, explained the purpose of the study, inquired about the candidates' interest in the study and asked permission to briefly assess their functional ability to determine eligibility. When the candidates declined to take part in the study, the researcher thanked them for their time and consideration. In the case of study candidates who failed to meet the inclusion criteria, the researcher again thanked them for their time and consideration and explained why they could not participate. For potential participants who expressed interested in the study and met the inclusion criteria, the researcher confirmed with them the details of the study, scheduled appointments, collected basic demographic information (e.g., name, age, diagnoses, other medical concerns, educational and musical background, preferred songs, etc.) and provided an informed consent form (Appendix B). All participants signed the consent form prior to beginning the study.

The researcher screened 51 potential participants through in-person recruitment meetings and excluded 17 individuals with right-hemisphere stroke, three individuals with bilateral stroke and six individuals with unknown diagnoses. Among study candidates who had experienced left-hemisphere stroke, 13 individuals who exhibited no symptoms of apraxia and three apraxia patients who demonstrated difficulty with verbal comprehension were excluded from the study.

Of the 13 potential participants who met eligibility criteria (four from the pre-existing KUMC study and nine from in-person recruitment), eight individuals consented to participate in this study with a total of seven participants completing all the assessments and interventions throughout the study. The recruitment and study participation process is outlined in Figure 1.

To compensate for participants' time, effort, and transportation costs for the roughly 10-week research period, compensation was rendered in the form of prepaid gift cards. Participants received a $20 gift card after completing visit 2 (pretest), an $80 gift card after completing visit 12 (posttest), and a $50 gift card upon completing visit 13 (follow-up test).

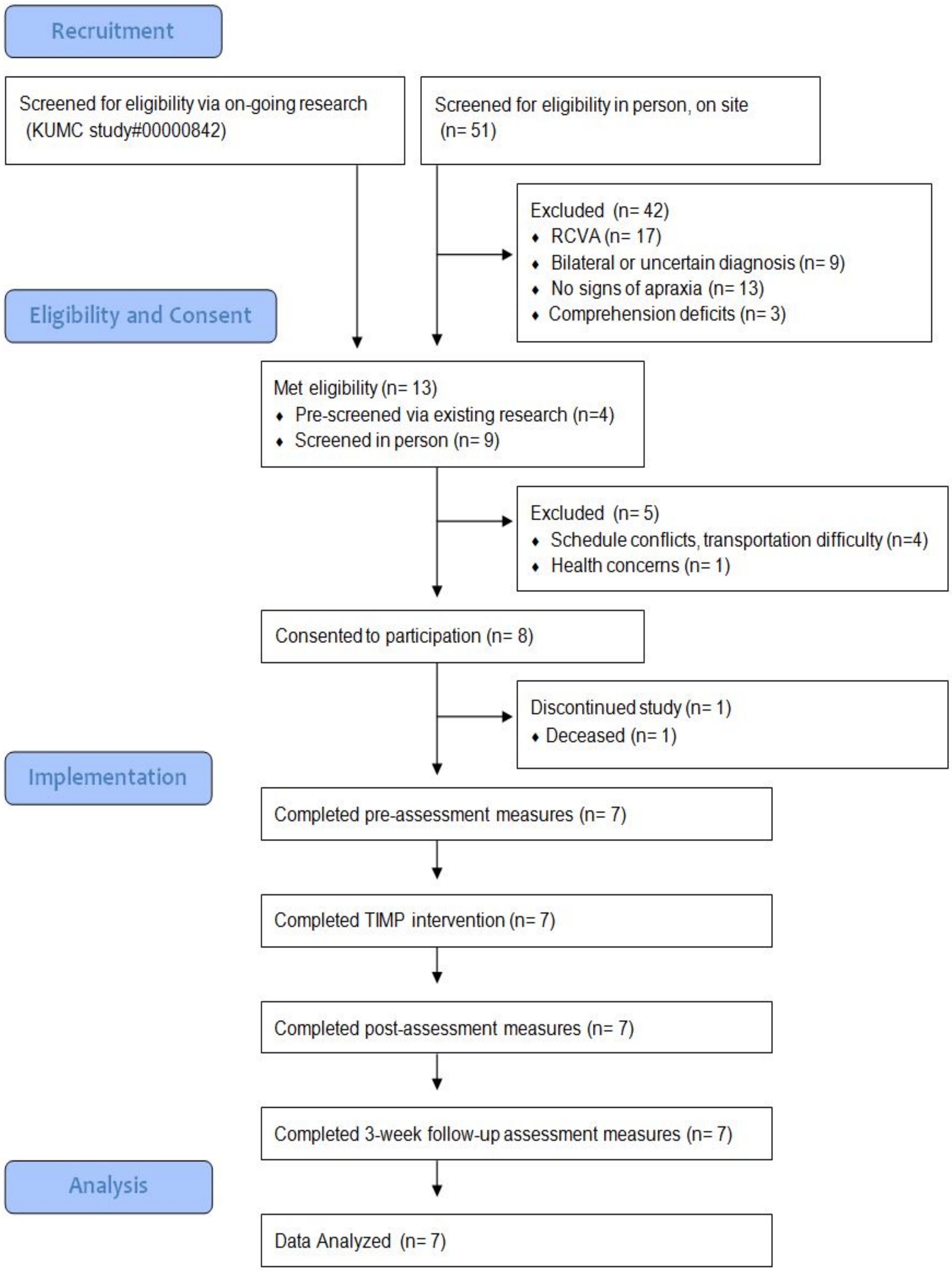


Figure 1. Participant flow chart diagram.

Participant Characteristics and Demographics

Table 1 provides an overview of the participants' characteristics and demographic information. Seven stroke survivors, four males and three females, participated in the study. The participants' ages ranged from 43 to 84 years of age at the time of the study; mean age was 58.7 years (SD=13.02) and median age was 57 years. All participants were left-hemisphere stroke (LCVA) survivors, as reported by the participants, their family members, or social workers. Due to paresis arising from LCVA, the participants (who were all right-handed) encountered more difficulties when using their contralateral right hands. Participants 1, 3, 4, and 5 demonstrated at least 30° of active shoulder flexion and 10° of active wrist extension but limited residual fine motor functions as evidenced by achieving less than 10° of extension of two fingers and thumb. Participants 2, 6, and 7, meanwhile, exhibited more than 90° of active shoulder flexion, more than 60° of active wrist extension, and more than 10° of active extension of each joint of all fingers.

All participants suffered from apraxia concurrently with paresis. Participants 4, 5, and 7 presented with moderate apraxia as evidenced by AST scores ranging from 6 to 8, while participants 1, 2, 3, and 6 presented with severe apraxia, scoring 1 or 2 on the AST baseline test score. In addition to motor apraxia, all participants also exhibited aphasia. Participants 1, 3, 4, and 5 simultaneously had apraxia of speech that was confirmed by reports from speech-language pathologists, family members or the participants themselves, as well as by clinical observations. In order to check their verbal comprehension skills, the researcher administered the WAB's Auditory Verbal Comprehension Test (yes/no question portion), which consisted of 20 questions pertaining to personal information, participants' immediate environments, and previously learned information (Appendix A). All participants were able to respond "yes" or "no" verbally and independently, with scores ranging from 45 (75%) to 60 (100%) out of 60. AST testing was administered four times throughout the study, and the resultant scores are described in the following Results section.

Participants had an average of 16.5 years of education years (starting from Kindergarten) (SD=2.25). All participants (with the exception of Participant 7, who had no musical background) had experience with some musical activities in their early years, such as learning to play musical instruments (e.g., violin, trumpet, tuba, or accordion) in elementary school or participating in choir at church. Participant 2 had the most pre-musical experience, having taught piano for over 20 years. None of the participants were involved in any other UE-related therapy programs while participating in the present study.

Table 1

Demographic Information and Characteristics of Participants

Participant	Age (yrs)	Gender	Time Since CVA Onset (yrs)	Education (yrs)	Shoulder Flexion ROM	Wrist Extension ROM	Apraxia Screening of TULIA Score	Auditory Verbal Comprehension Score
1	50	M	2.5	14.0	30	10	1	51/60 (85%)
2	84	F	6.0	16.0	150	60	2	45/60 (75%)
3	57	F	2.0	14.0	30	10	2	54/60 (90%)
4	49	M	1.0	18.0	80	10	7	60/60(100%)
5	43	F	1.5	21.0	30	10	8	57/60 (95%)
6	70	M	1.5	16.0	90	60	2	60/60(100%)
7	58	M	10.5	16.5	180	65	6	60/60(100%)
Mean	58.71		3.57	16.5				
SD	13.02		3.22	2.25				

Research Design and Procedure

The current study comprised a pilot study utilizing a small sample and a multiple pre- and post- measure design. A pilot study is a small-scale study used to assay methodology feasibility before proceeding to a larger-scale study that includes the assessment of the limited efficacy of outcomes measures (Tickle-Degnen, 2013). The pilot study thus comprises a necessary step in exploring the application of interventions in a new patient population (Leon, Davis, & Kraemer, 2011). While the current study included relatively small number participants within a single group, two separate assessments prior to the intervention were conducted to check for potential changes in variable(s) and to establish a stable baseline. Clinical outcomes of pre- and post-measures as well as a 3-week follow-up assessment were used to examine the efficacy of the intervention and its retention.

Prior to the intervention, individuals who consented to participate in this study underwent two pre- assessments, one week apart, that were administrated by the licensed occupational therapist. All research processes, including evaluations and intervention, were held in an 884-square foot private room. During the pre-test evaluations, participants were assessed for approximately one hour in four standardized UE functional tests and apraxia testing. In addition, each participant was asked to select his or her preferred songs for use in TIMP intervention (Appendix C) from a pre-selected song list created by the researcher and based on recommended musical repertoires for geriatric populations (VanWeelden & Cevasco, 2007). During the evaluation and intervention periods, participants were allowed to be accompanied in the room by a family member or social service assistant if they so desired.

Each participant attended a total of nine interventions, three times per week, over a span of three weeks. The researcher, a board-certified music therapist, provided these 1-hour individual TIMP interventions for each participant. Intervention scheduling was arranged before starting the intervention period. Scheduling changes were accommodated if requested in advance during the intervention period. No participant missed a scheduled intervention, with the exception of one instance where a participant had a health-related family emergency; a make-up session was subsequently provided. After completion of the final intervention, the same evaluator administered identical functional post-evaluation tests to each participant including UE functional tests and an apraxia test. In addition, participants were asked to complete a treatment fidelity questionnaire (Appendix C) to evaluate the TIMP intervention provided. More detailed information on intervention, fidelity, and outcome measures are described in the following section. A follow-up test was conducted three weeks after the posttest. All participants completed all four evaluation sessions as scheduled. The study timeline is displayed below (see Table 2).

Table 2

Timeline of the Study

	Week								
	1	2	3	4	5	6	7	8	9
Baseline assessment	✔								
Pretest		✔							
Intervention			✔	✔	✔				
Posttest						✔			
Follow-up test									✔

Outcome Measures

The outcome measures used to evaluate UE functions and functional application included the Fugl-Meyer Assessment, the Wolf Motor Function Test, the Box and Block Test, and the three UE related domains of the Stroke Impact Scale (i.e., strength, activities of daily living/instrumental activities of daily living (ADL/IADL), and hand function). Apraxia testing was administrated through the Apraxia Screen of TULIA. An occupational therapist, who had several years of working experience with neurologic disorders, conducted all functional tests throughout the study. The evaluation for the five functional tests was completed in one visit, which lasted approximately one hour for each participant.

Upper Extremity Function Testing

Fugl-Meyer Assessment. The current study used the Fugl-Meyer Assessment (FMA) to evaluate UE functions (Fugl-Meyer, Jaasko, Leyman, Olsson & Steglind, 1975). The FMA is generally considered the gold standard for measuring motor impairments in stroke patients and is widely used in both clinical and research settings (Gladstone, Danells, & Black, 2002). The FMA has excellent test-retest reliability (ICC=0.97), interrater reliability (ICC=0.97), construct validity (*r*=0.73-0.76), and content validity (Gladstone et al., 2002; Platz et al., 2005; Sanford, Moreland, Swanson, Stratford, & Gowland, 1993; Hsieh et al., 2009; Woodbury et al., 2008). The current study exclusively assessed UE functions (maximum score of 66), comprising upper arm function (maximum score of 36), wrist/hand function (maximum score of 24), and coordination/speed (maximum score of 6). The functions are rated on a 3-point ordinal scale (0=cannot perform, 1= performs partially, 2=performs fully), with higher scores indicating higher degrees of function.

Wolf Motor Function Test. The Wolf Motor Function Test (WMFT) was conducted to measure participants' UE motor ability through timed and functional tasks (Taub et al., 1993). The WFMT possesses excellent degree of test-retest reliability (r=0.95 and 0.90 for functional ability and performance time, respectively), interrater reliability (ICC=0.93 and 0.99 for functional ability and performance time, respectively), internal consistency (Cronbach's alpha=0.92), and adequate concurrent validity with FMA (r= -0.57) and is often used in laboratory-based settings in stroke-related research (Morris, Uswatte, Crago, Cook, Taub, 2001; Wolf et al., 2001). The test consists of 17 measuring items, including timed functional tasks and strength measures, as well as the quality of motor function for each of the timed tasks. The 15 tasks incorporate simple proximal movements and more complex distal movements of both unilateral and bilateral activities such as reaching, lifting a can, flipping cards, turning a key, folding a towel, and lifting a basket. Performance scores are determined by 1) measuring the performance time (WMFT-TIME) for completing each task and 2) grading each task on a functional ability scale (WMFT-FAS) for each task using 6-point ordinal rating scale: (0=does not attempt with involved arm, 5=movement appears normal). Shorter performance times and higher functional ability scores indicate higher UE functionality. For strength testing (WMFT-grip strength), the study utilized the Smedley Digital Hand Dynamometer model 12-0286 (Fabrication Enterprises Inc.), with the handle position set at medium for all participants' measurements. The grip strength value was expressed in pounds (maximum value of 198 pounds).

Box and Block Test. The Box and Block Test (BBT) was conducted to assess unilateral gross dexterity (Mathiowetz, Volland, Kashman, & Weber, 1985). Participants were asked to pick up one wooden cube (2.5cm) at a time and to move it from one designated compartment to another. The number of blocks the participant transferred in 60 seconds was scored for both the more affected and less affected extremities; higher scores in the BBT correspond to greater levels of hand function. The BBT has demonstrated excellent test-retest reliability (r=0.98 and 0.93 for more affected and less affected hand, respectively), interrater reliability (ICC=0.99), convergent validity with the FMA (r=0.92), and concurrent validity (Chen, Chen, Hsueh, Huang, & Hsieh, 2009; Lin, Chuang, Wu, Hsieh, & Chang, 2010; Platz et al., 2005).

Stroke Impact Scale. The Stroke Impact Scale (SIS) is a self-report assessment that evaluates the degree to which stoke has impacted patient health and quality of life by measuring the level of participation in life activities and relevant skills (Duncan et al., 1999). Of the eight domains in SIS, three domains related to UE functions were used for this study, including strength (4 items), activities of daily living/instrumental activities of daily living (ADL/IADL, 10 items), and hand function (5 items). Each item is rated on a 5-point Likert scale: strength is rated in terms of physical force (1=no strength at all, 5=a lot of strength) while ADL/IADL and hand function are rated in terms of difficulty (1=could not do at all, 5=not difficult at all). Higher scores indicate better function than lower scores reported as self-perception. For the aforementioned domains of strength, ADL/IADL and hand function, the SIS has demonstrated adequate to excellent test-retest reliability (ICC=0.70-0.92) and interrater reliability (ICC=0.61, 0.82 and 0.74, respectively), and excellent internal consistency (ICC=0.82, 0.87 and 0.95, respectively) (Carod-Artal, Coral, Trizotto, & Moreira, 2009; Duncan et al, 1999). The SIS has also shown excellent predictive validity (r=0.86) and good criterion validity (rho=0.51-0.68; p<0.01) for the measure of ADL/IADL and hand function subscale, respectively (Duncan et al., 1999; Kwon et al., 2006; Lin, & Fu et al., 2010).

Apraxia Testing

Apraxia Screen of TULIA. The study used the Apraxia Screen of TULIA (AST) to evaluate the scope of IMA in the participants (Vanbellingen et al., 2011). The AST is a shortened screening version of a test of upper limb apraxia (TULIA) (Vanbellingen et al., 2010) that features good validity and test-retest reliability (Vanbellingen et al., 2011). The 12 items in AST include one meaningless, three intransitive (communicative), and eight transitive (relating to tool use) gestures, either in imitation or pantomime situations. Participants were asked to use the ipsilateral (left) hand to execute the requested gestures while seated in front of the evaluator. Each task is scored on a dichotomous scale of either fail (score=0) or pass (score=1), with a maximum score of 12. Points are deducted if, during the performance of tasks, the patient commits body part as object errors or spatial errors, or performs extra movements/omissions, false end positions, substitutions and perseverations or movements not related to the desired gesture (e.g., amorphous or seeking movements). However, slight slowdowns or discrete errors (e.g., spatial error, extra movement or omissions) are allowed; if the brief errors (e.g., substitutions or perseverations) are corrected, the participant receives no score deduction.

In order to assess the participant's ability to understand pantomime actions, the researcher also administered the pantomime recognition test. Regarding the eight transitive gestures (pantomime & imitation) tested in AST, the evaluator pantomimed the eight tool actions and then asked participants to point to the photograph of the tool corresponding to the pantomime. The error examples for five items (glass, hammer, scissors, comb and screwdriver) were derived from the pantomime-to-photograph matching test of the Florida Apraxia Battery-Extended and Revised Sydney (Power, Code, Croot, Sheard, & Rothi, 2009; Rothi, Raymer, & Heilman, 1997), while error examples for the remaining three items were created by the researcher (Appendix D). The response was scored as 0=incorrect or 1=correct.

Intervention

The intervention for this study was designed to focus on UE exercises using TIMP to facilitate the rehabilitation of gross and fine motor skills in stroke patients with paresis and apraxia. In compliance with the music-based intervention reporting guidelines, the following information is described for detailed and transparent reporting of the intervention: intervention theory, intervention delivery, specifications for the interventionist, setting, intervention content, and treatment fidelity (Robb, Burns, and Carpenter, 2011).

Intervention Theory

The intervention in the current study targets stroke patients suffering from IMA. It should be noted that the use of music in this context is not intended to directly treat or correct IMA-related symptoms (i.e., gesture errors); rather, it seeks to utilize TIMP to improve UE functions (i.e. targeting UE paresis) in stroke survivors concurrently suffering from persistent IMA – a condition that hinders the planning and execution of desired movements, commonly manifesting as spatial and temporal errors.

The findings of previous basic and clinical research have supported the role of rhythm in motor rehabilitation while attesting to the positive effects of its clinical application (Magee et al., 2017; Moumdjian et al., 2017). In addition to solid evidence of neuroplasticity changes of auditory-sensorimotor connections in the brain (Altenmuller, et al., 2009; Fujioka et al., 2012; Grau-Sanchez et al., 2013; Jamali et al., 2014; Ripolles et al., 2016; Rodriquez-Fornells et al., 2012; Rojo et al., 2011), researchers have also amply documented the use of TIMP intervention as an effective tool for improving UE functions and daily living skills in stroke patients (Altenmuller et al., 2009; Raghavan et al., 2016; Schneider et al., 2010, 2007; van Vugt et al., 2014; Villeneuve et al., 2014).

In addition to potentially impacting motor functions in the brain, the use of musical cues in TIMP intervention can also facilitate the proper structuring of temporal, spatial, and force dynamics, thus regulating desired movement patterns. By having patients play instruments, the intervention aims to create motor entrainment and priming of the motor systems while generating auditory and kinematic feedback from the targeted instrument playing (Thaut, 2013). This process, in turn, facilitates the feedback/feedforward mechanism that helps patients to plan, execute, and monitor their functional movements (Mertel, 2014; Thaut, 2005). In essence, the temporal ordering of auditory patterns and the sequential patterned musical structures that are created when patients play instruments may be aimed at facilitating anticipatory planning execution in IMA sufferers (Thaut & McIntosh, 2014).

Moreover, the musical experience in rehabilitation has been associated with positive patient experience, emotional engagement and motivation, which may facilitate exercise repetition leading to positive treatment effects (Raghavan et al., 2016; van Vugt et al., 2014) and increase adherence to the therapy program (Street et al, 2018). In addition, incrementally increasing the direction or height of targets or rearranging the number or order of targeted contacts (or designated fingers) in instrumental playing (drum and keyboard) may help patients to more effectively (re)learn the desired functional movement patterns. In sum, TIMP intervention can provide post-stroke IMA sufferers with the necessary motivation and therapeutic framework to repetitively and diligently practice arm movements. TIMP regimens may thus lead to improved UE functions and functional skills, as evidenced by increased scores on functional arm, hand and ADL tests. Such improvements may be crucial precursors to the partial or full recovery of functional independence in patients with post-stroke IMA.

Intervention Delivery and Interventionist

The current study's TIMP intervention consisted of a total of nine individual sessions conducted three times per week, spread out over three consecutive weeks. Each session involved a one-hour period of TIMP intervention for each participant, provided by a researcher/interventionist. The interventionist in this study was an NMT-trained and board-certified music therapist with several years' experience working with individuals with neurologic disorders. The same interventionist facilitated all TIMP interventions throughout the study.

Setting

The TIMP interventions and evaluations of outcome measures took place in an 884-square foot room located on the first floor of the local rehabilitation community center (Figure 2). A drum set and a keyboard were placed in the middle of the room, with two rectangular tables measuring 71" (L) x 30" (W) x 29" (H) placed parallel to the right of the interventionist to accommodate other rhythmic musical instruments and supplies. The drum set, a keyboard, and tables were positioned in a semicircle for the participant's convenience of use, intervention order and movement. A sink for hygiene purposes was located in the corner of the room. During the interventions, the participant sat in front of the musical instruments, using a movable chair without armrests measuring 17" (L) x16" (W) x 37" (H). The interventionist sat either to the front or to the side of the participant to provide musical and/or physical facilitation. Specific exercises and limb use, as well as the distance, speed, or repetition of functional movements, were adjusted throughout the session, depending on each participant's functionality and needs as determined by the interventionist.

Figure 2. Picture of the TIMP intervention room.

Intervention Content

The TIMP intervention was aimed at facilitating UE functions, including gross and fine motor skills. The following section lists the specific details of the intervention content.

Intervention Materials and Music Delivery. Throughout the interventions, the participant played musical instruments such as drums or keyboard, primarily using the more affected arm (the therapist encouraged the involvement of the less affected arm as well, if needed). To facilitate the exercising of gross motor skills, the participant played on a Yamaha DTX 400K Electronic Drum set, with six pads placed at three different heights (two drum pads on both sides of the participant located at low, medium and high elevations). The specific height, width, and depth of the drum set were arranged in accordance with each individual's functional abilities and therapeutic purposes. The diameters of the drum pads were 10 inches for the two drum pads placed at the highest elevation and 7.5 inches for each of the other four pads. For fine motor exercises, participants used a Yamaha Piaggero NP11, a sixty-one- key portable digital keyboard. The keyboard measured 40" (W) x 4" (H) x 10" (D), with a 5-octave range from a low C to high C. During individual sessions, the interventionist provided musical facilitation on a thirty-six-steel string Oscar Schmidt wooden autoharp, featuring twenty-one chords: eight major, six minor, and seven seventh chords. A medium-gauge standardized size pick was used for the autoharp. The interventionist provided live musical accompaniment on either the autoharp (e.g., for facilitating the participant's use of the drum or keyboard) or the keyboard (e.g., for facilitating the participant's keyboard playing) by playing chords harmonized with the songs. Both the interventionist and the participant engaged in live singing and playing of musical instruments. Various supplementary instruments such as paddle drums, tambourines, xylophones, shakers, maracas, or castanets were also used for supplementary UE exercises in accordance with the individual therapeutic needs of each participant.

Music and Song Selection. Popular songs were utilized during the TIMP intervention, allowing the participant to engage in instrumental/singing accompaniment in order to more efficiently facilitate UE exercises and increase patient motivation. Most song choices were based on the participant's preferences as compiled during the initial evaluation. The participant was asked to select the songs that they liked best from a pre-selected list prepared by the interventionist (Appendix C). The song list included simple songs with distinct meters such as 2/4 or 4/4 (e.g., *Oh When the Saints Go Marching In, Country Roads*, etc.) and 3/4 meter (e.g., *Edelweiss,* etc.), to be employed functionally to facilitate simple and repetitive arm exercises. The interventionist also asked each participant to name a few favorite songs in addition to the listed selections. The choice of meter (e.g., 2/4 or 3/4, etc.) depended upon how well it matched the natural tendency of movement pattern. For example, a bicep movement exercise might be best facilitated through a song featuring 2/4 meter, while movement to a 3/4 meter might be more suited to an arm-swing motion. The participant's functional ability also determined the various adaptions that were used in the musical facilitation. For instance, while a 2/4 meter might typically be employed for a forward-reaching movement, a 6/8 meter might be more applicable for the participant in the same movement exercise for a participant who needs more information of movement due to decreased functional ability. The songs that were used for the drum and keyboard playing (and were chosen by participants) are presented in Tables 3 and 4.

Table 3

List of Songs Used for Drum Playing

Song Title
Abracadabra, Country Roads, Daisy Bell, Edelweiss, Deep in the Heart of Texas, Happy Wanderer, Here Comes the Sun, Hey Good Looking, Home on the Range, I Can See Clearly Now, I've Been Working on the Railroad, I Walk the Line, Jambalaya, Let it Be, My Bonnie Lies Over the Ocean, Row Row Row Your Boat, Oh Susanna, Oh What a Beautiful Morning, Oh When the Saints Go Marching In, Show Me the Way to Go Home, Side by Side, Sidewalks of New York, Spring in the Rockies, Swing Low Sweet Chariot, Take Me Out to the Ball Game, The Yellow Roses of Texas, When Jonny Comes Marching Home, With a Little Helps from My Friends, Yellow Submarine, and *You Are My Sunshine.*

Table 4

List of Songs Used for Keyboard Playing

Participant	Song Title
1	*Mary Had a Little Lamb* and *Row Row Row Your Boat*
2	*Mary Had a Little Lamb, Twinkle Twinkle Little Star, Row Row Row Your Boat, Ode to Joy, Do-Re- Mi Song, Happy Birthday to You, Old Macdonald Had a Farm*, and *Chopsticks*
3	*Itsy Bitsy Spider, Row Row Row Your Boat, Twinkle Twinkle Little Star*, and *Silent Night Holy Night*
4	*Itsy Bitsy Spider, Mary Had a Little Lamb* and *Chopsticks*
5	*Mulberry Bush* and *Twinkle Twinkle Little Star*
6	*Amazing Grace and Chopsticks*
7	*Twinkle Twinkle Little Star* and *Chopsticks*

TIMP Protocol. The current study relied mainly on drum and keyboard targeted to help improve gross and fine motor skills, respectively, based on the effectiveness of TIMP in previous research involving musical instruments (Altenmuller et al., 2009; Schneider et al., 2010, 2007). Each intervention consisted of a warm-up period, a period of functional UE exercises for gross and fine motor skills, and a cool-down period. TIMP was utilized in functional UE exercises for gross motor skills (step 2) and fine motor skills (step 3) as detailed below:

1. Warm-up: The interventionist established rapport with the participant through simple greetings or questions about his or her current status (e.g., feelings, physical issues, concerns, etc.) and helped the participant loosen muscles with simple stretching or neck rotation exercises.

2. Functional exercise for gross motor skills: The participant played rhythmic instruments such as a drum set with six drum pads to exercise his or her arms. In the case of the aforementioned drum set, the six drum pads were placed in different spatial positions horizontally and vertically. The participant was asked to engage in arm and shoulder exercises (e.g., elbow flexion/extension, shoulder abduction/adduction) while seated by playing the drum pads situated at different target locations. The arm movement-focused drum playing included 1) unilateral (playing one drum pad using the more affected arm) forward, vertical, lateral, and diagonal reaching; 2) a unilateral mix of vertical, lateral, diagonal reaching; 3) bilateral (playing two drum pads symmetrically while using both two hands on each individual pad) forward, vertical, diagonal reaching; and 4) a bilateral mix of vertical, diagonal reaching drum playing (Appendix C). A mallet or adapted mallet featuring a sponge-wrapped handle to facilitate grasping was used in these exercises. Once the participant became comfortable with the reaching movements for one target drum pad, the interventionist progressively increased the complexity of playing by adding several targets with increased height or width movement patterns (e.g., progressing from playing one pad to playing four pads). If the interventionist determined that more advanced exercises or further repetitions in addition to the drum playing were required, the participant was encouraged to practice the targeted movements with other rhythmic instruments such as paddle drums, tambourines, xylophones, shakers, maracas, or castanets. Descriptions of simple reaching exercise examples using musical instrument playing are displayed in Table 5.

3. Functional exercise for fine motor skills: In order to practice fine motor skills, the participant was asked to play the keyboard. If necessary, exercises for hand and wrist flexion/extension movements (Table 5), followed by finger exercises, preceded the keyboard playing. Finger exercises began by focusing on each individual finger, either playing a single note once (e.g, thumb) or repetitively (e.g., thumb-thumb-thumb-thumb). This was followed by exercises using several fingers to play several notes (i.e., from two to five notes) in the following permutations: 1) consecutive playing: fingers playing adjacent notes in succession (e.g., thumb-index, thumb-index-middle); 2) interval playing: fingers playing notes in succession with spatial interval(s) between fingers (e.g., thumb-middle, thumb-middle-pinky); and 3) chord playing: two or more fingers playing notes simultaneously (e.g., thumb-index, thumb-index-pinky) (Appendix C). Similar to the administering of the gross motor exercises, the degree of task difficulty and complexity were gradually increased and the participant was asked to repeat the practice of the targeted tasks before moving on to the next task. After the simple finger exercises, the participant was asked to play his or her choice of a simple children's song from the song list, which was organized by the interventionist according to the participant's functional ability (e.g., the number of fingers used, intervals). Some examples of easy songs are *Mary Had a Little Lamb* and *Ode to Joy*, while more difficult songs include *You Are my Sunshine, Amazing Grace,* or *Chopsticks*. Examples of the songs that were used for keyboard playing are presented in Appendix C.

4. Cool-down: After intensive UE training, the session wrapped up with a deep- breathing exercise.

Table 5

Description of Motor Functional Exercises

	Example of music-playing exercise
Biceps curl	The seated participants hold one or two hands at their sides, with the option of holding a mallet. They are asked to vertically lift their hand(s) (or mallet) to play a target instrument located by their shoulder (elbow flexion/extension).
Forward reaching	Seated participants are asked to extend their arm forward from their body to hit an instrument (shoulder/elbow extension), and to then pull their arm (or mallet) back toward their body.
Vertical and horizontal reaching	Seated participants are asked to raise their arm vertically above their head, with the option of holding a mallet, and then back down (shoulder flexion), or to stretch their arm downward and backward and then back to the original position (shoulder extension), or out to their side at shoulder height (shoulder abduction) and then back in, striking an instrument at each extreme position (up, down, out and in). Participants are also asked to shake small instruments by moving their arms in a circular motion at shoulder height.
Diagonal reaching	Seated participants are asked to move their arm upward at a diagonal angle to play one instrument above the head, and then back down to the opposite side below the waist to play the other instrument. Based on each participant's needs, participants can stretch out a theraband in a diagonal direction above the head before releasing it.
Lateral reaching	Instruments are held by the interventionist on both the left and right sides of the participants. Participants are asked to hit both instruments horizontally (shoulder external/internal rotation) by moving their arm with or without a mallet from side to side. Based on each participant's ability, the reaching distance to instruments can be changed to increase the difficulty, if needed.
Bilateral arm movement	Participants are asked to play instruments with both their left and right arms, with or without mallets, simultaneously or alternately. They can assist their more-affected arm with their less-affected arm.
Wrist flexion and extension	Participants are asked to place their palm facing down and to play two instruments while hitting targets as they move their wrist up (extension) and down (flexion).
Hand pronation and supination	Participants are asked to rotate their hand from a palm-down position (pronation) to a palm-up position (supination). Participants will play the instrument(s) by hitting it as a target, alternating between hitting with the palm and the back of the hand.

Musical Facilitation of TIMP. Throughout the entirety of each session, the interventionist utilized musical (temporal, spatial, and force) cues with the help of an autoharp (mainly for the drum pad playing) or keyboard (mainly for the keyboard playing) in order to provide information of movement to the participant regarding the speed, direction and force of movement, as well as the range of motion. Based on the natural tendency of a particular movement pattern, the interventionist determined the meter of the music accordingly. The participant was allowed to establish his or her natural tempo, after which the interventionist played simple improvised rhythmic patterns or/and pre-composed selections from a list of each participant's favorite songs that seemed best suited to the movement pattern. Meanwhile, the tempo was matched to the participants' own speed and was gradually adapted to the desired functional speed and goal. To facilitate spatial aspects of movements against gravity (e.g., upward/outward arm movements), the interventionist played strongly accented beats and ascending melodic lines with increasing volume, while employing descending lines and decreasing volume for movements under gravity (e.g., downward/inward movements). Loudness and tension in musical progressions were represented by muscle contraction, while softness and musical resolution were depicted through relaxation in movement. The interventionist also played arpeggios to employ an extensive range of pitches (strings) for motions requiring a broad range of movement.

While playing the drum pads for gross motor skills, various reaching movements were facilitated by songs in 2/4 meter (Table 3). For the full movement range of reaching out and back, the interventionist used songs in 6/8 meter in order to provide the participant with sufficient time to reach out to hit the target (duration of 3 beats) and return the arm to the staring position (duration of 3 beats). During the finger exercises, the interventionist generally used the keyboard to accompany participants' targeted movements facilitating the participants' lifted, upward finger movements through a strong accented harmony chords. A steady, strong beat could also be provided to help the priming and initiation portions of the exercise. While the participant was playing a single note (e.g., C), a few notes alternately (e.g., C and G), or harmonic chords (e.g., C major chord), the interventionist played the participant' preferred song melody or some variations on the songs (e.g., variation on *Twinkle Twinkle Little Star*), or provided improvisational accompaniment (e.g., pentatonic scale), thereby increasing the participant's motivation and repetition of exercises. When the participant played his/her chosen songs (i.e., melody of the song) on the keyboard, the interventionist provided the musical cues via corresponding harmonic chords. Along with musical cues, the interventionist also provided positive verbal feedback and cues, in addition to rendering physical prompting and assistance when needed.

Treatment Fidelity

Treatment fidelity is designed to ensure that treatment is implemented as originally conceptualized and intended (Hildebrand et al., 2012; Robb et al., 2011). In particular, Robb et al. (2011) recommend assessing treatment delivery and provider (interventionist) training in music-based intervention studies. Rehabilitation intervention literature also stresses that the assaying of adherence (i.e., the degree to which the therapist delivers the intervention as specified) and competence (i.e., the proficiency with which these techniques are implemented) is crucial for treatment fidelity, especially in evidence-based practice (Hildebrand et al., 2012).

To help ensure the proper fidelity strategies for treatment delivery in this study, each participant was asked to complete a fidelity form created by the researcher of the current study. Appendix C provides a copy of the proposed questionnaire, which consists of nine items pertaining to the TIMP intervention procedures the patient experienced after the completion of all intervention sessions (e.g., the training component for each step of the protocol, musical facilitation). The ratings were analyzed by calculating response percentages (i.e., the number of "yes" responses were divided by the total number of questions, then multiplied by 100). In addition to the treatment fidelity checklist, the study also included a manualized protocol (Appendix C) and a control variable of a single provider/interventionist who was a board-certified music therapist with standarized NMT training and several years' of clinical experience with populations suffering from neurologic disorders.

Data Analyses

The data for baseline, pretest, posttest, and follow-up UE assessment using FMA, WMFT, BBT, strength, ADL/IADL, and hand domains of SIS were analyzed through descriptive analyses as well as visual graphs. Each participant's raw score and the mean score of all participants were displayed in a lined graph that charted the narrative description of each participant's score change, percentage change, as well as the mean change (trend). A correlation was performed to determine the relationship between post-intervention UE functional test changes. Differences between baseline and pretest scores on UE functional measures were compared to control for the passage of time during no-treatment periods. The scores for follow up testing were also used to investigate the persistence of TIMP intervention results. Data for AST were compared across time to verify the existence of persistent apraxia throughout the study. Further, study participants were divided into three UE motor-based categories according to FMA-UE cutoff scores (Fugl-Meyer et al., 1975; Velozo & Woodbury, 2011): 0 to 20 (severe), 21 to 50 (moderate), and 51 to 60 (mild). The study also examined UE functional outcome changes (after intervention, posttest results) regarding participants' functional status.

In addition to the descriptive analyses, the measures of FMA, WMFT, BBT, and SIS (i.e., strength, ADL/IADL, and hand function domains) were also analyzed using a series of 2-tailed, paired sample *t*-tests to examine the differences in mean scores of all participants between pre- and post-treatment changes. These included, in particular, differences between baseline and pretest, pretest and posttest, pretest and follow-up test, and posttest and follow-up test. Considering that nonparametric analysis can provide an alternative approach for a small sample size study (De Winter, 2013), the researcher of the study further conducted the Mann Whitney U test for findings that were significantly different from the paired sample *t*-test analyses in order to partially relax the assumptions of the paired sample *t*-test and to rule out potential false positives. However, it must be emphasized that the results of the current study's statistical analyses should be interpreted with caution, as misreading the statistical results of such as a small sample size could spawn type II error. Accordingly, the researcher would not recommend any generalization of the therapeutic effects derived from this study.

CHAPTER 4

RESULTS

This study was designed to examine the potential of TIMP to exert positive changes on UE motor function in post-stroke patients suffering concurrently from paresis and IMA. In reporting the findings of this investigation, the first section of this chapter presents the outcomes of UE functional measurements following TIMP intervention. Next, the researcher presented additional information concerning UE outcome changes reflecting participants' functional status. The second section reviews the apraxic testing results, while the final section provides information on the findings of the treatment fidelity assessment. Raw data for each functional test are presented in Appendix E.

Upper Extremity Functions

The findings for performance in upper extremity functions include the narrative descriptions as well as visual graphs depicting score changes for all participants, including the mean changes for the four functional UE measurements: Fugl-Meyer Assessment (FMA); Wolf Motor Function Test (WMFT); Box and Block Test (BBT); and the strength, activities of daily living/instrumental activities of daily living (ADL/IADL) and hand domains of the Stroke Impact Scale (SIS). The FMA results are followed by subdivision function analyses (e.g., distal and proximal), while BBT measuring unilateral function includes the results for both the more affected and less affected sides.

Fugl-Meyer Assessment

The FMA was administered to examine each participant's motor impairment and recovery. The total FMA scores spanning assessments for each of the seven study participants, including the mean scores of all participants, are presented in Figure 3. Data for all participants showed positive gains in UE functions after the TIMP intervention. Between pretest and posttest, Participants 4 and 5, who scored low in baseline UE functions, exhibited the greatest increases in UE functionality, as evidenced by changes of 32.26% and 37.50%, respectively. Participant 7, meanwhile, demonstrated the lowest increase (1.64%) in UE function. Four out of seven participants (Participant 1, 2, 4, & 6) demonstrated continuance of increase or maintenance of positive changes even after termination of the TIMP intervention, with Participant 1 marking a 20% post-intervention increase.

The results of the *t*-test analyses indicated significant differences in the average FMA score of all participants between pretest and posttest ($p \leq .01$), and between pretest and follow-up ($p \leq .05$) (Table 6). There was no significant difference between baseline and pretest ($p = .689$). The non-parametric Mann-Whitney U test results showed significant differences in FMA scores between pretest and posttest ($p \leq .01$) and between pretest and follow-up test ($p \leq .05$).

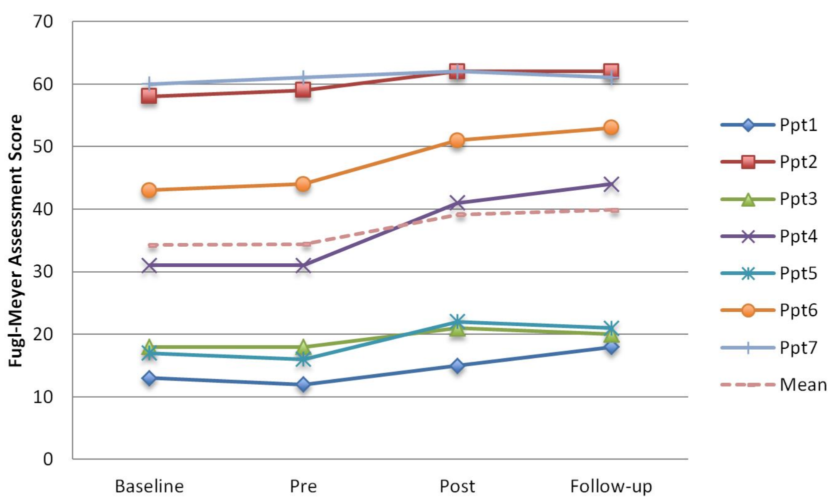


Figure 3. Changes in Fugl-Meyer Assessment scores across time.

Table 6

Effect of TIMP Intervention on Fugl-Meyer Assessment

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	34.29	19.70	0.42	6	0.69	7
Pre	34.43	20.52				
Pre	34.43	20.52	4.03	6	0.01**	7
Post	39.14	19.98				
Pre	34.43	20.52	3.24	6	0.02*	7
FW	39.86	19.81				
Post	39.14	19.98	1	6	0.36	7
FW	39.86	19.81				

*$p \leq .05$. **$p \leq .01$.

Since the FMA consists of proximal (upper arm) and distal (wrist/hand) functions, additional analysis was conducted. Figure 4 presents the proximal scores in FMA across time, with all participants exhibiting increases in proximal function between pretest and posttest. While the percentage of increase varied for each participant, ranging from 10 to 30%, Participant 1 (31.00%) and Participant 5 (27.27%) demonstrated the largest positive increases following TIMP intervention. Participant 7, who had a high raw score (raw score 34) at both baseline and pretest, showed no change at posttest. Participants 1, 2, 4, and 6 were able to maintain their improved upper arm functions at the 3-week follow-up test, exhibiting changes of 7.69%, 0.00%, 11.54%, and 7.69%, respectively.

Paired sample *t*-test results are reported in Table 7. While no significant difference was observed between baseline and pretest ($p = .689$), there were significant positive changes in participants' proximal functions at posttest ($p \leq .01$) and at the 3-week follow-up ($p \leq .05$). The results of the Mann-Whitney U test also demonstrated the significant differences between pretest and posttest ($p \leq .05$), and between pretest and follow-up test ($p \leq .05$).

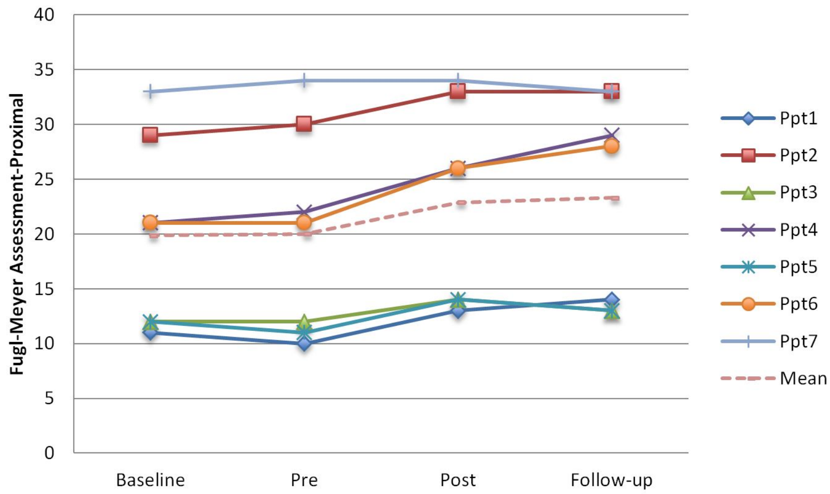


Figure 4. Changes in Fugl-Meyer Assessment scores (proximal) across time.

Table 7

Effect of TIMP intervention on Fugl-Meyer Assessment (proximal)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	19.86	8.11	0.42	6	0.69	7
Pre	20.00	8.83				
Pre	20.00	8.83	4.80	6	0.00**	7
Post	22.86	8.46				
Pre	20.00	8.83	2.91	6	0.03*	7
FW	23.29	8.79				
Post	22.86	8.46	0.70	6	0.51	7
FW	23.29	8.79				

*$p \leq .05$. **$p \leq .01$.

Figure 5 displays the changes in individual participants' upper distal function as well as the mean score for distal function of all participants. Participants 3, 4, and 5, who exhibited minimum residual wrist/hand functions at baseline, increased their distal function after TIMP intervention by 16.67%, 66.67%, and 60.00%, respectively. In contrast, the percentage of increase at posttest for Participants 6, 7, and 2 were 8.70%, 3.70%, and 0.00%, respectively. Follow-up test data indicated that the participants maintained their increased wrist/hand functions for three weeks post-intervention. Only Participant 1 demonstrated increased function at his follow-up test, despite no changes in his scores at posttest.

No significant difference in the distal functions of the participants was found between baseline and pretest of the *t*-test analyses ($p = 1.00$). However, there was a significant difference between pretest and follow-up test ($p \leq .05$) (Table 8). The Mann-Whitney U test also yielded significant positive increases in distal function between pretest and follow-up test ($p \leq .05$).

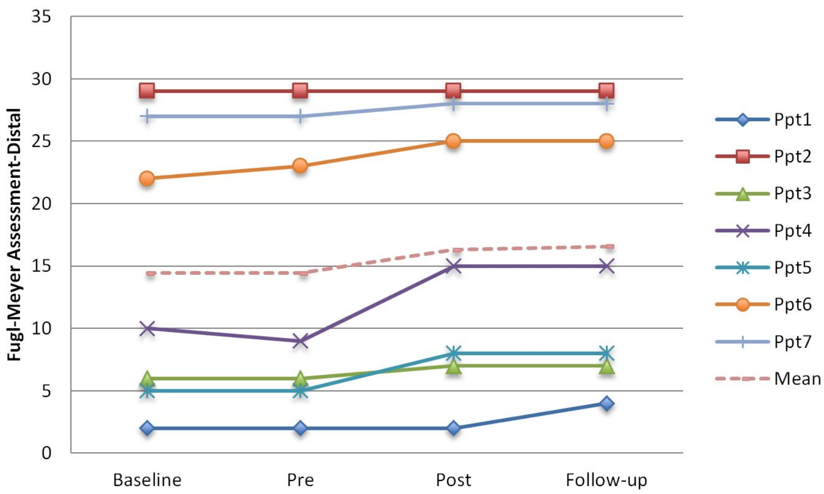


Figure 5. Changes in Fugl-Meyer Assessment scores (distal) across time.

Table 8

Effect of TIMP intervention on Fugl-Meyer Assessment (distal)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	14.43	10.43	0.00	6	1.00	7
Pre	14.43	10.61				
Pre	14.43	10.61	2.32	6	0.06	7
Post	16.29	10.25				
Pre	14.43	10.61	2.90	6	0.03*	7
FW	16.57	9.87				
Post	16.29	10.25	1.00	6	0.36	7
FW	16.57	9.87				

*$p \leq .05$.

Wolf Motor Function Test

The WMFT results encompass participants' performance time (WMFT-TIME) and functional ability (WMFT-FAS) for completing the function-based tasks. Findings for strength (WMFT- grip strength) were presented separately, measuring the maximum amount of force produced during a palmar grip.

WMFT-TIME. Some data was missing for WMFT-TIME measurements, as some participants were unable to complete tasks within the 120-seconds time limit due to individual functional limitation. Accordingly, a robustness check was implemented for the missing data analysis. Descriptive data with the imputed values (e.g., 120 seconds) and without the imputed values are presented in Appendix E. While a decreased change indicated increased UE functions, the overall participant data for WMFT-TIME demonstrated large decreases after TIMP intervention (Figure 6). All participants decreased their performance time at posttest, with changes ranging from -31.82% to -58.72%, but the majority of study participants marked slight increases ranging from 1.23% to 30.37% at the 3-week follow-up when performing the same tasks. Participants 3 and 6 showed continuous positive gains by displaying the decreases of -23.35%, and -21.94%, respectively, at the follow-up. The participants exhibited a strong correlation (r= .90) between WMFT-TIME and FMA scores (Appendix E).

The participants marked significant positive gains in their WMFT-TIME scores between pretest and posttest ($p \leq .05$), and between pretest and follow-up ($p \leq .05$), while no difference between baseline and pretest (p= .80) was found in the t-test analyses (Table 9). The non-parametric Mann-Whitney U test results demonstrated no significant differences between pretest and posttest and between pretest and follow-up test.

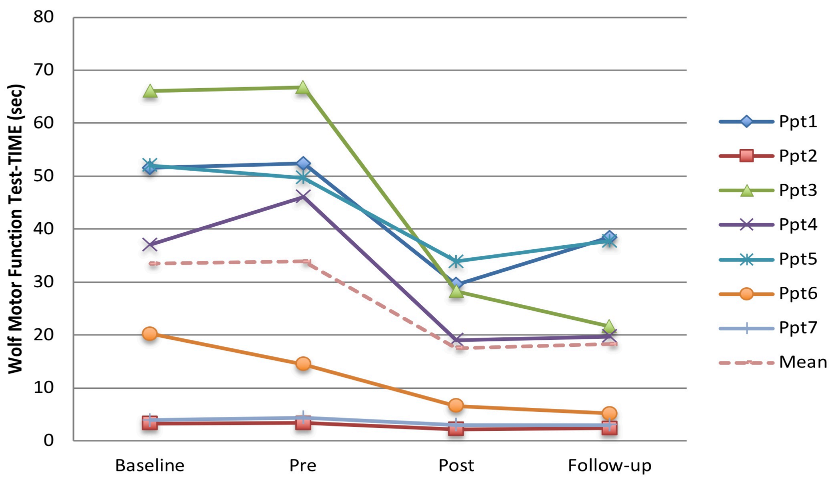


Figure 6. Changes in Wolf Motor Function Test scores (time) across time.

Table 9

Effect of TIMP intervention on Wolf Motor Function Test (time)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	33.43	22.99	0.26	6	0.80	7
Pre	33.87	23.89				
Pre	33.87	23.89	3.10	6	0.02*	7
Post	17.49	12.49				
Pre	33.87	23.89	2.64	6	0.03*	7
FW	18.30	14.43				
Post	17.49	12.49	0.45	6	0.67	7
FW	18.30	14.43				

*$p \leq .05$.

WMFT-FAS. Positive gains were observed in results for WMFT-FAS, which measured participants' movement quality during the completion of the tasks (Figure 7). While all participants demonstrated increases in quality of movement at posttest, the greater increases were found in Participant 1 (155%), Participant 5 (150%), Participant 3 (91.95%), and Participant 4 (65.36%). Participants continued to mark increases from posttest to follow-up test ranging from 1.46% to 13.07% changes, except for Participant 3 (0%) and 5 (0%) and Participant 7 (-1.57%).

Table 10 shows that paired sample *t*-test analyses yielded significant differences in participants' mean scores of WMFT-FAS between pretest and posttest ($p \leq .01$) and between pretest and the 3-week follow-up test ($p \leq .01$). No significant difference was observed between baseline and pretest ($p = .27$). Results of the Mann-Whitney U test showed no significant differences between pretest and posttest and between pretest and follow-up test.

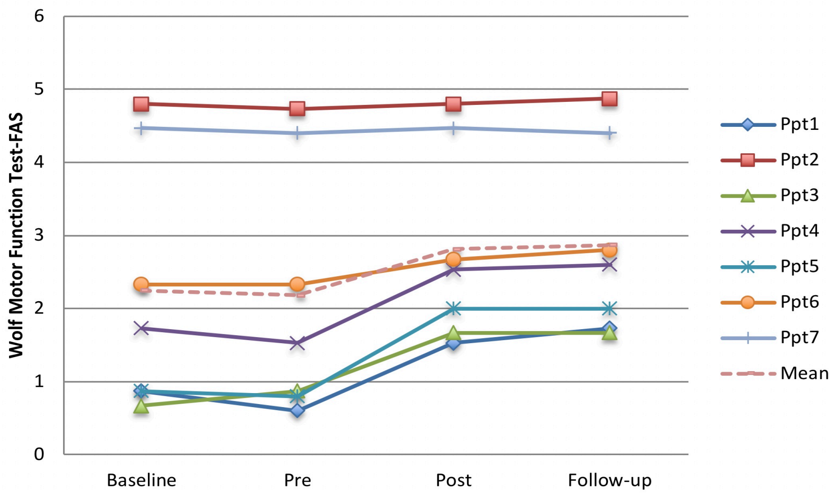


Figure 7. Changes in Wolf Motor Function Test scores (FAS) across time.

Table 10

Effect of TIMP intervention on Wolf Motor Function Test (FAS)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	2.25	1.60	1.21	6	0.27	7
Pre	2.18	1.60				
Pre	2.18	1.60	3.59	6	0.01**	7
Post	2.81	1.14				
Pre	2.18	1.60	3.71	6	0.01**	7
FW	2.87	1.19				
Post	2.81	1.14	1.68	6	0.14	7
FW	2.87	1.19				

**$p \leq .01$.

WMFT-Grip strength. Overall, an increasing trend was observed in the mean scores of all participants' grip strength of their more affected side (Figure 8). However, grip strength results revealed some variability among the participants, perhaps because individual functional abilities in combination with paresis may have made it more difficult for some individuals to utilize their hand functions. Participant 1 showed a large increase of 75.00% at posttest, but demonstrated a 72.45% decrease at the follow-up test. Meanwhile, the grip strength data for Participant 2 and 3 displayed decreases at posttest but increases at the at 3-week follow-up. Participant 7, who exhibited high-functioning UE ability at baseline, demonstrated an increase in grip strength after TIMP sessions (5.13%) and a decrease (4.07%) at the follow-up test. No statistically significant changes were found in any of the *t*-test analyses (Table 11).

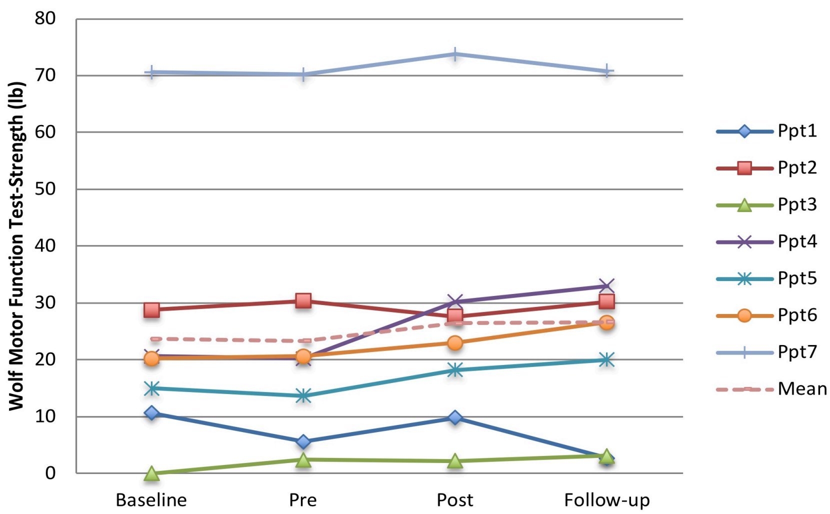


Figure 8. Changes on Wolf Motor Function Test scores (grip strength) across time.

Table 11

Effect of TIMP intervention on Wolf Motor Function Test (grip strength)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	23.69	20.90	0.43	6	0.69	7
Pre	23.30	21.08				
Pre	23.30	21.08	2.04	6	0.09	7
Post	26.40	21.39				
Pre	23.30	21.08	1.65	6	0.15	7
FW	26.63	21.30				
Post	26.40	21.39	0.16	6	0.88	7
FW	26.63	21.30				

Box and Block Test

Figure 9 displays the BBT results for the more affected extremity (right hand) of each participant, including the mean scores of all participants across time. As the BBT assessed dexterity, the results for the participants' right hands revealed a high correlation with those of FMA ($r = .93$) and WMFT-FAS ($r = .95$). Overall, participants displayed an increasing trend in gross dexterity following TIMP intervention. The scores of Participants 2, 6, and 7 were above average (Figure 9). Data for Participant 1 and 5, who both had very limited hand/finger functionality, demonstrated no score changes across time while Participant 4 dramatically increased his right hand's functionality by moving five blocks at posttest, compared to zero blocks at pretest however, this increase was diminished at the 3-week follow-up.

In the *t*-test analyses, participants showed increased dexterity skills, with right-hand dexterity posting significant gains both at posttest ($p \leq .05$) and three weeks later ($p \leq .05$), but exhibiting no significant difference between baseline and pretest ($p = .60$) (Table 12). The Mann-Whitney U test results demonstrated the significant difference between pretest and posttest ($p \leq .05$), and between pretest and follow-up test ($p \leq .05$).

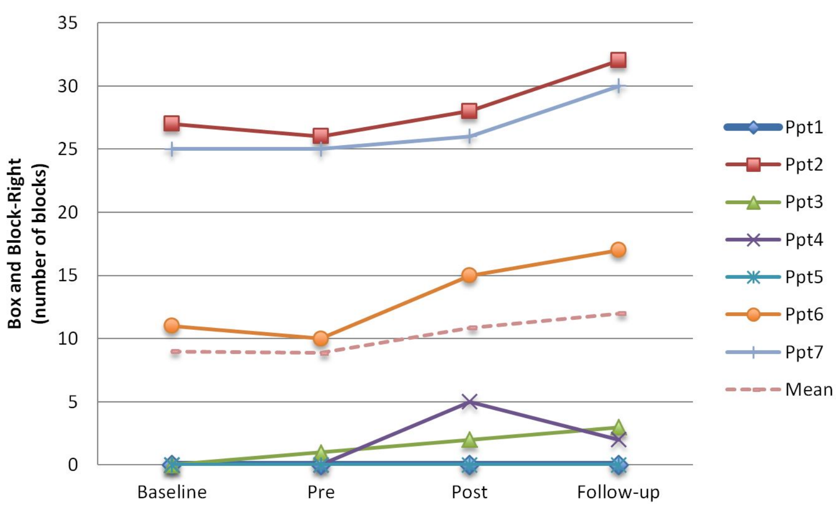


Figure 9. Changes in Box and Block Test scores (right) across time.

Table 12

Effect of TIMP intervention on Box and Block Test (right)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	9.00	11.39	0.55	6	0.60	7
Pre	8.86	11.04				
Pre	8.86	11.04	2.45	6	0.05*	7
Post	10.86	11.27				
Pre	8.86	11.04	2.91	6	0.03*	7
FW	12.00	13.19				
Post	10.86	11.27	1.22	6	0.27	7
FW	12.00	13.19				

*$p \leq .05$.

The study additionally used BBT to investigate left-hand dexterity for comparison with right-hand functionality (Figure 10). Participants with more challenging UE impairment, namely Participants 1, 3, 4, and 5, demonstrated a greater degree of functional differences between their more-affected and less-affected sides. Comparing the functions to age and gender as matched to that of healthy adults, BBT data for all participants was 2-3 times lower than the normative data, even though the left hand was the participant's' less-affected side (Mathiowetz et al., 1985). Overall, participants displayed an increasing trend in score changes from baseline, through pretest, to posttest. Interestingly, *t*-test and Mann- Whitney U test analyses showed significance differences in participants' left-hand dexterity prior to intervention ($p \leq .01$) and after the intervention ($p \leq .05$) as well (Table 13).

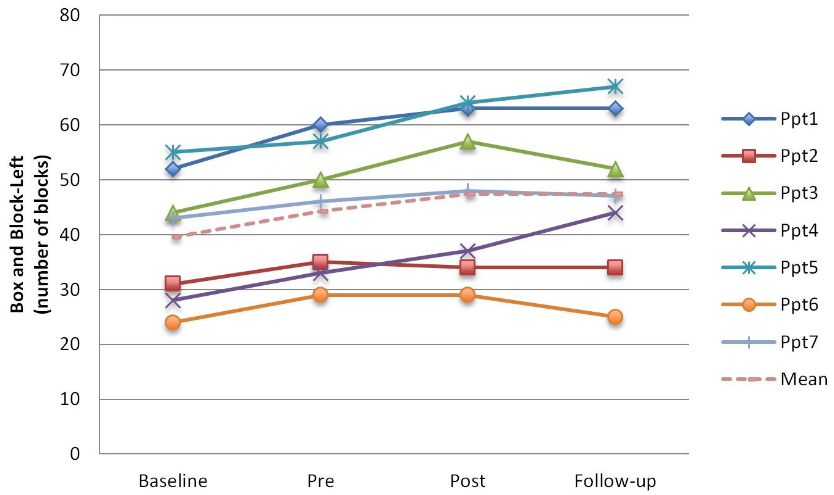


Figure 10. Changes on Box and Block Test scores (left) across time.

Table 13

Effect of TIMP intervention on Box and Block Test (left)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	39.57	11.17	6.31	6	0.00**	7
Pre	44.29	11.28				
Pre	44.29	11.28	2.65	6	0.04*	7
Post	47.43	13.30				
Pre	44.29	11.28	1.51	6	0.18	7
FW	47.43	13.84				
Post	47.43	13.30	0.00	6	1.00	7
FW	47.43	13.84				

*$p \leq .05$. **$p \leq .01$.

Stroke Impact Scale

Three domains of SIS (strength, ADL/IADL, and hand functions) were administered in this study in order to examine participants' perceived UE-related functions. The findings of each domain are presented separately below.

Strength. The perceived rating scores of strength for all participants, including the mean scores, are presented in Figure 11. Most of the participants displayed an overall increasing trend in mean scores, with Participant 2 and 3 marking large increases at posttest of more than 30%

and 100%, respectively. The score of Participant 4 did not change at posttest but increased 66.67% 3 weeks later, while Participant 1 similarly demonstrated a 25.00% positive increase, but only at the follow-up test. The data of Participant 7, who had posted maximum scores at baseline, indicated no change across the time. The mean strength scores in SIS were highly correlated with the mean scores in WMFT-FAS (r= .80) and BBT (r= .80).

Significantly different results in participants' strength subscale in SIS only appeared between pretest and the follow-up in the t-test analyses ($p \leq .05$) (Table 14). A significant difference between pretest and the follow-up was also found in the Mann-Whitney U test results ($p \leq .05$).

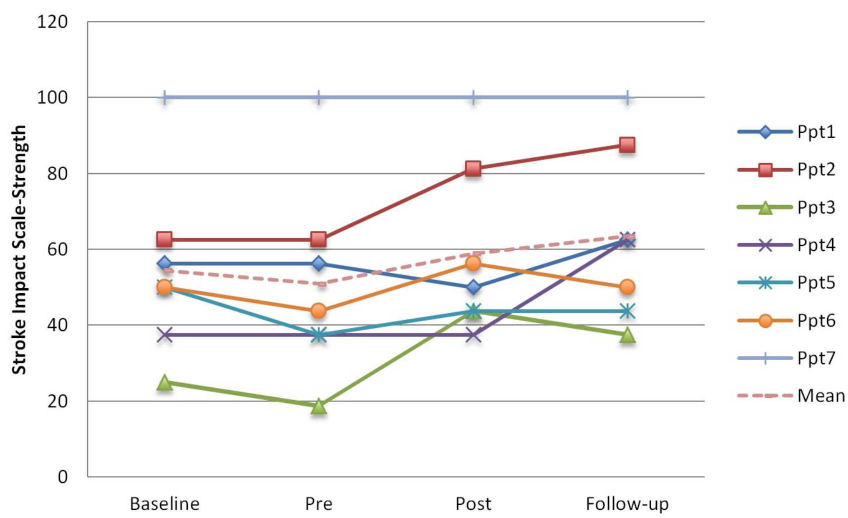


Figure 11. Changes in Stroke Impact Scale scores (strength) across time.

Table 14

Effect of TIMP intervention on Stroke Impact Scale (strength)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	54.46	21.83	1.92	6	0.10	7
Pre	50.89	23.96				
Pre	50.89	23.96	1.89	6	0.11	7
Post	58.93	21.35				
Pre	50.89	23.96	3.24	6	0.02*	7
FW	63.39	21.24				
Post	58.93	21.35	1.05	6	0.33	7
FW	63.39	21.24				

*$p \leq .05$.

Activities of Daily Living/Instrumental Activities of Daily Living. Participants' rating scores indicated positive increases in ADL/ADL skills after TIMP intervention and at the 3-week follow-up (Figure 12). Participants 1, 2, 5, and 6 showed greater increases of SIS-ADL/IADL at posttest, marking changes of 36.34%, 10.34%, 15.00% and 42.36%, changes, respectively. Only Participant 3 showed a slight decrease (3.57%) at posttest, but otherwise demonstrated an 18.52% increase at the follow-up.

Table 15 demonstrates the findings of *t*-test analyses. While the results show no significant change in the average scores of participants for SIS-ADL/IADL between baseline and pretest ($p= .75$), significant positive changes were found between pretest and posttest ($p\leq .05$), between pretest and follow-up test ($p\leq .01$), and between posttest and follow-up test ($p\leq .01$). On the other hand, the non-parametric Mann-Whitney U test yielded significant differences between pretest and follow-up test ($p\leq .01$), and between posttest and follow-up test ($p\leq .05$), but not between pretest and posttest ($p= .06$), suggesting that TIMP intervention may provide only long-term improvement.

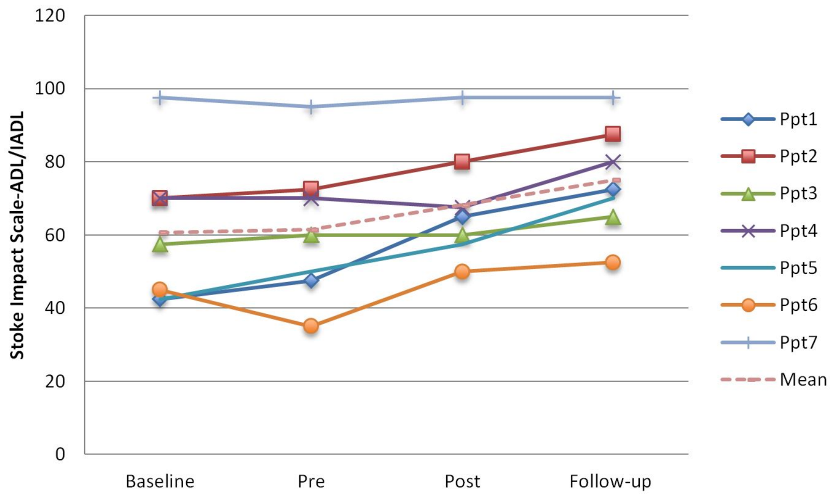


Figure 12. Changes in Stroke Impact Scale scores (ADL/IADL) across time.

Table 15

Effect of TIMP intervention on Stroke Impact Scale (ADL/IADL)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	60.71	18.69	0.33	6	0.75	7
Pre	61.43	18.32				
Pre	61.43	18.32	2.41	6	0.05*	7
Post	68.21	14.74				
Pre	61.43	18.32	4.41	6	0.00**	7
FW	75.00	12.87				
Post	68.21	14.74	3.80	6	0.01**	7
FW	75.00	12.87				

*$p \leq .05$. **$p \leq .01$.

Hand. The data for SIS hand functions, including the mean scores of all participants, are presented in Figure 13. Participants showed positive increases in perceived hand functions, including Participant 1, who showed a 66.67% increase at posttest. Participants 3 and 5 did not increase their scores at posttest, but demonstrated increases of 20% and 200%, respectively, at the follow-up. Participant 4 demonstrated limited wrist/hand function at baseline but more than doubled his percentage increase in perceived hand skill following TIMP intervention, with effects for 3 weeks. The participants' perception of hand skills was highly correlated with scores in WMFT-FAS (r= .83), BBT (r= .83), and SIS strength skills (r= .82). No statistically significant change was found in any of the *t*-test analyses (Table 16).

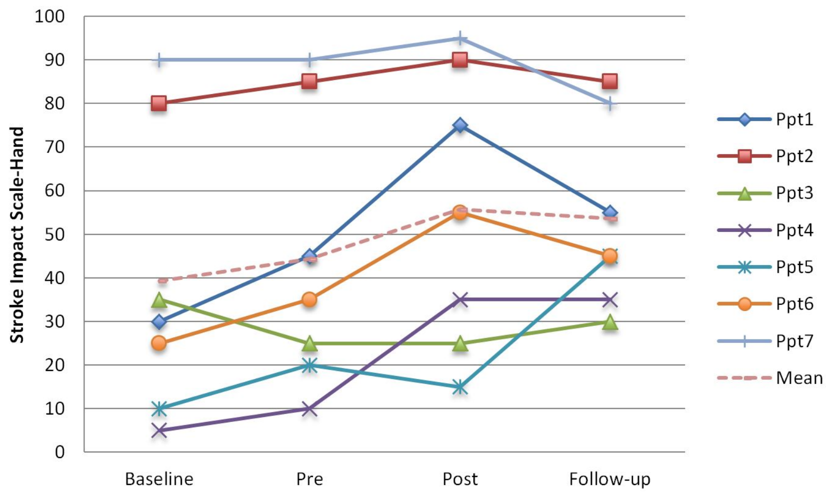


Figure 13. Changes on Stroke Impact Scale scores (hand) across time.

Table 16

Effect of TIMP intervention on Stroke Impact Scale (hand)

	Mean	SD	*t*	*df*	*p*	Observations
Baseline	39.29	30.64	1.62	6	0.16	7
Pre	44.29	29.21				
Pre	44.29	29.21	2.25	6	0.07	7
Post	55.71	29.57				
Pre	44.29	29.21	1.93	6	0.10	7
FW	53.57	19.77				
Post	55.71	29.57	0.34	6	0.74	7
FW	53.57	19.77				

Functional Status and Changes in Participants' Performance

The current research involved seven participants whose UE functional abilities varied at baseline. Accordingly, for the purpose of this analysis, in order to further examine the changes of therapeutic outcomes based on functional status, study participants were divided into three UE motor-based categories according to FMA-UE cutoff scores: 0 to 20 (severe), 21 to 50 (moderate), and 51 to 60 (mild). Participant 1, 3, and 5 were categorized as severely affected, Participants 4 and 6 were deemed moderately affected, and Participant 2 and 7 were considered as mildly affected.

The participants' average change in UE functional level between pretest and posttest is presented in Table 17. Following TIMP intervention, severely affected participants demonstrated average positive functional changes in WMFT-FAS (130.67%), BBT (103.67%), WMFT-TIME (45.73%), SIS-hand (27.77%), FMA (26.09%), SIS-strength (16.67%), and SIS-ADL/IADL (9.88%). Positive gains for moderately affected participants were seen in BBT (100%), SIS-hand (100%), WMFT-TIME (57.66%), WMFT-FAS (34.72%), FMA (22.67%), SIS-Strength (15.38%), and SIS-ADL/IADL (11.9%). Mildly affected participants showed increases in WMFT-TIME (33.25%), SIS-strength (11.54%), SIS-ADL/IADL (5.97%), BBT (5.88%), SIS-hand (5.71%), FMA (3.33%), and WMFT-FAS (1.53%). Percentage change scores in mildly affected participants were lower than for other participants in all outcome measures. Increased percentage changes in severely affected participants were greater than those in moderately affected participants in all measures except for WMFT-TIME and SIS-hand. Severely impaired participants exhibited the largest gains in both movement quality (WMFT-FAS) and overall UE impairment (FMA), as evidenced by changes of 130.67% and 26.09%, respectively. Moderately affected participants, on the other hand, showed greater improvement in hand functions, with increases of 100.00% in both BBT and SIS-hand functionality.

Table 17

Functional Level and Mean Score Changes between Pretest and Posttest

	FMA	WMFT-TIME	WMFT-FAS	BBT	SIS-Strength	SIS-ADL	SIS-Hand
Severe	4.0 (26.09)	25.73 (45.73)	0.98 (130.67)	0.33 (103.03)	8.33 (22.21)	8.33 (15.87)	8.33 (27.77)
Moderate	8.5 (22.67)	17.46 (57.66)	0.67 (34.72)	5.00 (100.00)	6.25 (15.38)	6.25 (11.90)	22.50 (100.00)
Mild	2.0 (3.33)	1.30 (33.25)	0.07 (1.53)	1.50 (5.88)	9.38 (11.54)	5.00 (5.97)	5.00 (5.71)

Figures in parentheses indicate participants' mean percentage change (%)

Apraxia Testing

Apraxia testing was administrated through the Apraxia Screen of TULIA (AST). The participants' AST scores ranged from 1 to 8, with the cut-off score for apraxia set at < 9 (Table 18). Even though there were slight changes in scores and an increasing score trend spanning four separate measures, all participants continued to experience persistent IMA, as evidenced by the entirety of scores coming in below 9. The AST score showed that Participants 1, 2, 3, and 6 suffered from severe apraxia as measured by AST scores of less than 5. Participants 4, 5, and 7 suffered from moderate apraxia, posting AST scores of between 5 to 8. The main apraxic errors exhibited by patients with moderate apraxia included those affecting spatial, positioning factors, internal configuration and amplitude. Participants with severe apraxia demonstrated additional deficits in imitation, content errors such as non-related, non-recognizable gestures, as well as a lack of response. Participants committed more errors during tasks related to transitive (tool-related) gestures than during tasks involving intransitive (e.g., non-symbolic or commutative gestures) imitation or gestures.

Table 18

Scores for Apraxia Screening of TULIA

Participant	Baseline	Pre	Post	Follow-up
1	1	1	3	3
2	2	1	2	1
3	2	2	2	4
4	7	7	8	8
5	8	7	7	5
6	2	1	5	5
7	6	7	8	8

In order to assess participants' level of comprehension regarding AST-tested competencies, a pantomime-to-photograph test was administered using photos of eight transitive items utilized in AST (Appendix D). Table 19 displays the participants' raw scores and the percentage of tasks successfully responded to in the pantomime-to-photograph test. The participants posted an average score of 6.43 out of 8 (80.4%) (SD=0.88), with raw scores ranging from 5 to 8.

Table 19

Pantomime-to-Photograph Test

Participant	1	2	3	4	5	6	7
Score (%)	5/8(62.5%)	5/8(62.5%)	6/8(75%)	7/8(87.5%)	7/8(87.5%)	7/8(87.5%)	8/8(100%)

Treatment Fidelity

After TIMP intervention, all seven participants completed the researcher-generated treatment fidelity form to verify whether the treatment was delivered as intended (i.e., whether the interventionist followed the intervention procedures) during the intervention (Appendix C). The three family members/caregivers who observed the interventions also participated in the treatment fidelity assessment, resulting in 10 total responses included for analysis. Fidelity scores were calculated by adding up all listed questions that elicited a "yes" answer, dividing the sum by the total number of questions, then multiplying the quotient by 100 to obtain a percentage. The consequent findings are provided in Table 20. All 10 respondents scored all of the listed questions as having been completed 100% of the time.

Table 20

Results of Treatment Fidelity

List of Questions	Responses (%)	
	Yes	No
Provided all four steps of TIMP protocol	100	0
Provided various arm exercises (i.e., drum playing) for gross motor skills	100	0
Increased the complexity of drum playing	100	0
Provided chances to practice drum playing	100	0
Provided various finger exercises (i.e., keyboard playing) for fine motor skills	100	0
Increased the complexity of keyboard playing	100	0
Provided chances for practicing for keyboard playing	100	0
Provided musical prompts/cues	100	0
Utilized the participants' preferred songs	100	0

Clinical Observations and Participants' Perceptions of Intervention

Clinical Observations

Participants demonstrated increased self-motivation and engagement in music activities over the course of the intervention period. Heightened self-motivation to play the instruments was evidenced by expressions of willingness to play or sing beyond the originally prescribed exercise parameters. For example, Participant 1, who suffered from severe aphasia and speech apraxia, spontaneously began singing while playing a song (*Row, Row, Row Your Boat*) on the keyboard. The parent of Participant 1 confirmed afterward that her son, who typically did not participate actively in other related programs, enjoyed the music intervention. Participant 3, an active participant in church choirs prior to her stroke, also engaged in lively singing during the exercise (although she displayed limited speech skills due to aphasia and speech apraxia). In spite of limited residual wrist/hand functions, Participant 4 expressed his interest in practicing his fine motor functions via keyboard playing. Such gains were not limited to self-motivation: Participant 6, for example, exhibited a boost in positive engagement in the activities. Participant

6 frequently expressed frustration about his motor impairments and demonstrated unstable emotional states by engaging in abrupt bouts of crying and shouting, which mostly occurred at baseline and pretest. During the intervention (specifically when he played his favorite song, *Amazing Grace,* on the keyboard), he reported that music helped him to deal with his feelings, participated in instrumental playing without commenting negatively about his functions, and expressed his willingness to participate in the intervention for a longer time.

Reports from Participants

Following completion of the TIMP intervention period, the participants were asked to describe their intervention experiences. Although all participants had some difficulty speaking due to aphasia or apraxia of speech, each individual nevertheless sought to verbally articulate his or her experience. These sentiments touched on the perceived effectiveness, enjoyment and playfulness, motivation and engagement, and overall satisfaction in regard to TIMP intervention. Included below are some of the comments from participants and family members/caregivers regarding these areas:

<u>Effectiveness</u>

[participant] *I think it helped my fine motor skills; this (the hand) is especially working better now.*

[participant] *The drum and ocean drum were helpful.*

[participant] *Very good, it helped*.

<u>Enjoyment and Playfulness</u>

[participant] *I enjoyed the music. The drumming was really good.*

[participant] *Time flies when you're having fun!*

[family member] *She really enjoyed it.*

Motivation and Engagement

[caregiver] *She wants more. She was very willing to be fully engaged. She was very enthusiastic about communicating, and showed desire to fully participate, which was a very positive thing.*

[participant] *I really liked it, I want to continue it,,, I'm looking forward to seeing you again.*

[participant] *I loved it, I wish I could do it more. So much better than before.*

Satisfaction and Appreciation

[participant] *You (the interventionist) were very good. I know it, you know it. Thank you!*

[participant] *Oh, it was great. She (interventionist) did terribly well!*

[family member] *Thank you for picking ___ (name) for this (program). (It was) really great.*

Clinical observation and the participants' own reporting confirmed that participants and family members/caregivers favorably assessed both the role that music played in facilitating the UE exercises and the their emotional experience with the intervention. Researcher and participant reportage also reflected participants' perception of the TIMP intervention as essentially beneficial and indicated increased motivational drive, which aligned with the feelings of enjoyment and playfulness reported by participants about the exercises. Additionally, not a single session was cancelled or missed by participants throughout the intervention period, indicating a high level of adherence to the program. Finally, participants and family members/caregivers strongly expressed a desire to continue the intervention after the study's conclusion by requesting suggestions for future exercises, and also asserted their strong intent to recommend the program to others.

CHAPTER 5

DISCUSSION

This study examined the potential of Therapeutic Instrumental Music Performance (TIMP) intervention to improve Upper Extremity (UE) functions in patients suffering from Ideomotor Apraxia (IMA) following stroke. The results of the present study indicated that after the TIMP intervention, study participants manifested positive gains in gross and fine motor skills and in perceived Activities of Daily Living/Instrumental Activities of Daily Living (ADL/IADL) skills. These improvements were confirmed by an array of testing methods, including impairment-based testing such as the Fugl-Meyer Assessment (FMA), function-based assessments such as the Wolf Motor Function Test (WMFT) and Box and Block Test (BBT), as well as a self-perceived motor and daily function test, the Stroke Impact Scale (SIS). In addition, such increased outcomes persisted at 3-week follow-up testing even as the Apraxia Screen of TULIA (AST) scores revealed that all participants demonstrated the apraxic impairments across time. Thus, despite the persistence of IMA, the overall results provide emerging evidence of TIMP's efficacy in improving UE functions and perceived ADL skills in stroke patients.

Moreover, by investigating intervention effects for patients afflicted by stroke-related comorbid disorders, the present study seeks to address the conspicuous lack in the literature regarding this population and its treatment. IMA is one of the most common post-stroke consequences, adversely affecting motor functions and daily functioning of up to half of all stroke survivors (Bienkiewicz, et al., 2014; Hanna-Pladdy et al., 2003; Sunderland & Shinner, 2007). In addition to stroke-induced paresis in their contralateral (right) UE, study participants displayed IMA deficits as confirmed by AST testing. Consequently, IMA patients were unable to perform certain actions or command, even though they understood it. However, all of the participants had been unaware of certain comorbidities affecting them adversely, as those conditions had gone undiagnosed – and thus untreated – by other health-related professionals, an apparently common occurrence in the larger IMA patient population (Bickerton et al., 2012; Civelek et al., 2015; Donkervoort et al., 2000; Kaya et al., 2006; Zwinkels et al., 2004). Indeed, the participants were unaware of these underlying conditions until the study's apraxia testing procedure had been implemented. This general lack of identification and patient awareness suggest that the presence of IMA with hemiparesis could conceivably hinder the potential rehabilitation benefits of efficient treatment interventions (Unsal-Delialioglu et al., 2008; Wu et al., 2014).

It was not the intent of this study to design a treatment regimen specifically targeting IMA-related impairments (such as problems with hand gestures). IMA has been recognized in the literature as a disorder that renders persistent impairment in its sufferers (Bickerton et al., 2012; Donkervoort, et al., 2006), a characterization that is congruent with the results of the present study wherein all participants continued to experience the persistent IMA across time. Thus, rather than treating IMA directly for curative purposes, this study was focused on using TIMP interventions to explore rehabilitation options that might allow stroke survivors to improve their UE skills and functional performance despite persistence of IMA. Indeed, TIMP has previously resulted in successful therapeutic outcomes for stroke-induced paresis in stroke survivors (Altenmuller et al., 2009; Raghavan et al., 2016; Schneider et al., 2010, 2007; Tong et al., 2015; van Vugt et al., 2014; Villeneuve et al., 2014). As study participants suffered concurrently from post-stroke paresis and IMA, TIMP intervention offered a promising rehabilitative approach, especially considering the well-addressed therapeutic rationales for incorporating music into motor rehabilitation, including auditory couplings, motor-learning principles, rhythmic stimulus and emotional benefits. The study outcomes thus provide encouraging evidence of the therapeutic efficacy of TIMP intervention for post-stroke patients suffering from these specific comorbidities, as well as evidentiary motivation for TIMP's expanded application in clinical use and research.

Functional Outcomes of Therapeutic Instrumental Music Performance

While all participants demonstrated substantial improvements in UE outcome measures, variability emerged within the findings of those outcome measures across participants. This variability may be linked to the nature of the TIMP intervention applied in the study due to differences in the participants' UE functional abilities. During the TIMP intervention, each participant was assigned at different level of task difficulty for their gross and fine motor exercises according to their functional abilities. For example, Participant 3, who had limited fine motor function, practiced a variety of reaching movements for gross motor skills, engaging in bicep exercises and forward, lateral, and diagonal reaching. Conversely, only one or two fingers were used for keyboard playing, resulting in more pronounced increases in gross motor skills but also discrepancies in results for the fine motor assessment. In comparison, Participant 6 exhibited distinct positive gains across a variety of functional assessments after the intervention, during which he practiced all protocol stages/steps for gross (e.g., both uni- and bilateral movements) and fine motor (e.g., use of all fingers) skills. Accordingly, given the breadth of such functional variations among participants, the intervention within the TIMP protocol (Appendix C) was malleably applied through individual intervention considering each person's discrete needs and abilities, which may have ultimately led to variability in functional UE outcomes.

Motor impairment findings appeared to demonstrate significant motor improvement, as indicated by increased FMA scores at posttest ($p \leq .01$) and 3-week follow-up test ($p \leq .05$). Despite variability in the level of score increases among individuals, all participants exhibited motor improvement, including in gross and fine motor functions. Interestingly, substantial gains were observed for FMA-proximal ($p \leq .05$) and FMA-distal ($p \leq .05$) at posttest and at follow-up test, respectively, supporting the assumption that recovery proceeds in a proximal (gross motor)-to-distal (fine motor) fashion (Fugl-Meyer et al., 1975; Gladstone et al., 2002). Furthermore, FMA data of two participants (i.e., Participants 2 and 7), who had relatively greater motor functionality and high baseline scores, supports the argument that FMA may encounter a ceiling effect when assessing fine motor skills (Thompson-Butel, Lin, Shiner, & McNulty, 2015). While no participants participated in any form of rehabilitation after completing the intervention period, the observed increases demonstrated continued improvement, in spite of individual variability. As suggested by these outcome measures, the findings thus support the argument that such intervention may provide therapeutic benefit for patients.

The observed changes in the WMFT at posttest revealed improvements in both motor functional ability and in the movement time that participants needed to complete tasks. Given the relationship between the two components of WMFT − time and FAS (functional ability scale) − results with an inverse relationship as shown in the study represent the most desirable outcome following intervention. All participants demonstrated observable increases in FAS scores and decreases in time as described by each component tested and by composite scores. The current study observed a higher percentage change in FAS scores (68.57%) than in timed scores (44.75%), which appears inconsistent with the results of earlier CIMT studies on long-term stroke patients that observed less robust gains in FAS as compared to WMFT time in cases where the training (CIMT) emphasized the number of repetition of each task (e.g, speed) (Taub, Lum, Hardin, Mark, & Uswatte, 2005; Wolf et al., 2006). Considering that TIMP facilitates desired movement patterns within a timing structure while emphasizing spatial positioning (Thaut, 2015), the technique may have spurred increased efficiency in participants' targeted movements as demonstrated by increased FAS scores and decreased task time. Although substantial clinical gains in FAS and TIME were evident ($p \leq .05$ by *t*-test analyses), these changes were not statistically significant when analyzed through non- parametric Mann Whitney U test. This may be attributable to the fact that participants with higher UE functions demonstrated minimal changes across time, even while exhibiting steady increases (Figures 6 and 7). However, the mean FAS and time change scores of participants in the current study (0.63 points and 16.39 seconds, respectively) met the established criteria for minimal detectable change in FAS and time (0.37 points and 4.36 seconds, respectively) as well as the minimum threshold for a clinically important difference (0.2~0.4 points and 1.5~2.0 seconds, respectively) (Lin et al., 2009). These findings suggest that, following intervention, participants achieved real performance gains (unattributable to measurement error) and clinically relevant change, supporting the argument for further integration of TIMP into research and clinical practice with the aim of achieving meaningful improvement in stroke patients with a paresis and apraxia.

The SIS measures evaluate how participants perceive their functions to have been impacted by stroke. While the SIS-ADL findings in the current study demonstrated an increasing trend immediately after intervention, even more substantial improvement was observed at the 3-week follow-up ($p \leq 0.01$). The longer-term intervention effect for SIS measures was consistent with the findings of a previous study that had shown significant improvements in SIS-ADL/IADLs only at the 1-year follow- up (Raghavan et al., 2016). As SIS measures are typically evaluated at 3-month intervals (Duncan et al., 1999), the posttest evaluation during the 3-week interval between pretest and posttest may have occurred too soon to allow substantial functional changes to be perceived by participants, who may have demonstrated more significant improvement as time passed. In addition, SIS- hand outcomes demonstrated less significant gains after intervention as compared to other functional outcomes, thus producing statistically insignificant results in the non-parametric analyses. Considering that SIS is measured by the participants' self-perception, these results may be partly due to participant variability in responsiveness to change. For example, Participants 3 and 5 in particular may not have perceived their fine motor skills to be sufficient, despite having increased their fine motor skills as evidenced by FMA-distal (wrist/ hand) results. While fine motor skills are essential in performing daily tasks, participants (especially those who exhibited limited wrist and hand functions) may have been overly sensitive and cautions about expressing their functions and therapeutic gains, which may have affected the current study results in turn.

The study also revealed an unexpected significant gain in BBT assessment results ($p \leq .01$) for participants' less affected left side prior to intervention (the intervention mainly focused on participants' contralateral right arm). Although purely speculative, the provenance of these pre-intervention changes in left hand function may relate to potential training effects. Upon repetition of the same test, participants may have been sufficiently familiar with the testing procedure to be motivated to check whether their left hand functioned better than the right, since other functional measures mostly evaluated the latter extremity (which was the more affected side that frequently elicited the participants' frustrations). Perhaps more significantly, such pre-intervention change was not observed in participants' more affected right side. Instead, progressing from the stable baseline, the mean differences in results for the right hand demonstrated significant functional gains after intervention, with the increased function maintained for three weeks ($p \leq .05$), which is a desirable outcome. While increased gains were found in both left and right hand functions across time, these findings may partially support the intention of the intervention and its therapeutic efficacy as submitted in this study.

Interesting findings were observed upon analyzing the functional changes in light of UE paresis status (Figure 14). Specifically, following intervention, observable functional gains were found in moderately (i.e., Participants 4 and 6) to severely (i.e., Participants 1, 3, and 5) impaired participants, whereas individuals who exhibited higher UE functions at baseline (i.e., Participants 2 and 7) demonstrated little change across time. Given that mildly affected Participants 2 and 7 scored close to the maximum prior to the intervention, this higher functional condition may have contributed to their limited outcome changes. Another observation related to the improved functional areas in response to participants' current abilities. Severely impaired participants, who demonstrated limited gross motor functions with greater motor impairment at baseline, exhibited the largest gains in movement quality (WMFT-FAS) as well as in overall UE functions (FMA). While greater improvement in hand functions (BBT and SIS-hand) was observed in moderately affected participants (who displayed low initial levels of fine motor function), it should be noted that stroke survivors with comparable functionality are frequently targeted in studies addressing fine motor skills (Taub, Uswatte, & Pidikiti, 1999; Villeneuve et al., 2014; Wolf et al., 2006). Although these findings were extracted from a small sample, they nevertheless provide useful data points for future studies of functional levels and of the specific targeting of areas that may ultimately generate tangible benefits from similar interventions.

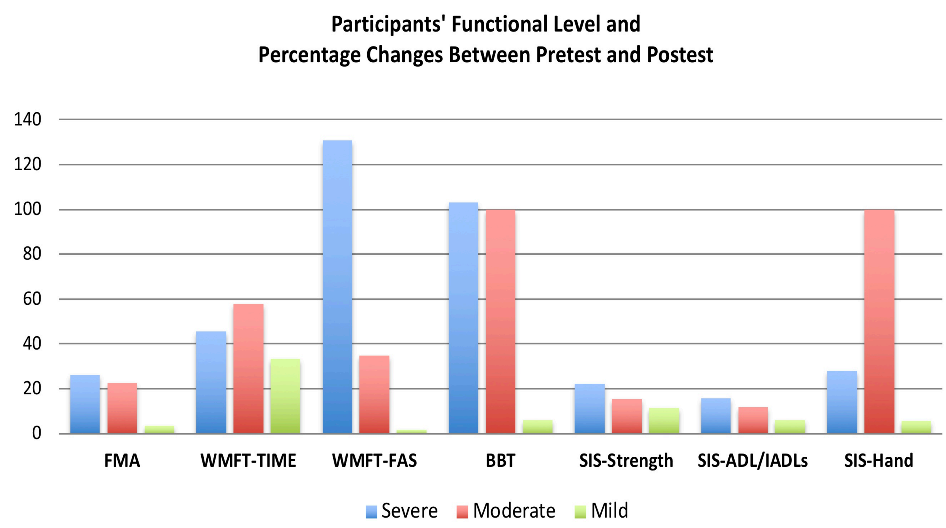


Figure 14. Functional level and percentage changes between pretest and posttest.

The third finding related to the UE functional status concerns the marked improvements found in severely affected participants (i.e., Participants 1, 3, and 5). Earlier studies have argued that stroke patients with less UE impairment, who are commonly predicted by FMA impairment severity, have a greater likelihood of better clinical outcomes (Gebruers, Truijen, Engelborghs, & De Deyn, 2014; Winters, van Wegen, Daffertshofer, & Kwakkel, 2014). However, the current study results reveal observable increases in severely affected participants, whose functional gains were higher or comparable to those in moderate participants. This outcome is in line with the findings of Raghavan et al. (2016), who similarly reported greater reductions in motor impairment in lower-functioning stroke patients than in those with higher functionality following an intervention that utilized the playing of music instruments (though it should be noticed that the functional range of lower-functioning in the earlier study was broader and study participants suffered from paresis only). While the notion is purely speculative, one potential explanation for the pronounced improvements in severely affected participants may include emotional considerations and/or individual motivation. Clinical observations and self-reporting both reflect the positive perceptions of participants and family members toward the intervention, as indicated in increased motivation/ engagement and enjoyment as well as observable clinical benefits. Throughout the individual TIMP intervention period, participants consistently commented on how meaningful and enjoyable they and their family members found the experience to be. While those with more challenging functional impairments may have expressed their satisfaction more frequently than mildly impaired participants, family members reported that participants with lower functionality were typically less engaged in regular activities in their lives due to functional limitations and reduced confidence. This consideration should be taken into account thoroughly for future studies. Given the important role that emotional considerations can play in music therapy for stroke patients (Nayak et al., 2000; Raghavan et al., 2016; van Vugt et al., 2014), the satisfying emotional engagement and motivation gleaned from such experiences may contribute to pronounced treatment effects.

In the final analysis, the study's findings support the potential therapeutic efficacy of TIMP-related treatment effects for stroke patients who suffer concurrently from paresis and IMA. Despite variability among participants in terms of functional abilities and score changes in outcome measures, individuals with a variety of functional UE levels, in spite of the persistent presence of IMA, demonstrated overall substantial functional gains in their UE functions. In particular, individuals with higher initial levels of motor impairment at baseline, including moderately to severely affected participants, experienced larger increases in UE functions, suggesting the potential benefits of TIMP intervention for individuals with relatively limited UE function, including remediation of paresis. Although IMA-related rehabilitation is still in its nascent stages, the development of innovative treatments to address this complex comorbid disorder will ultimately play a crucial role in the future of stroke rehabilitation.

Implications

This study comprises merely an initial step toward considering a treatment regimen for a specific population, and as such, may provide only limited efficacy in treatment effects. Nevertheless, it offers new information and insights on the implementation of TIMP for post-stroke IMA patients in both research and clinical settings in some important aspects: by providing initial findings for an unexamined IMA population, by investigating the intervention effects across various functional levels, by encouraging a heightened awareness of considerations for this population, and by suggesting TIMP's practical implications and potential applications for the MT profession.

This exploratory study encompasses new information that points to the potential for stroke rehabilitation efforts to germinate future streams of research. Relatively few studies have closely examined the practical consequences of stroke in music therapy literature, despite the considerable number of stroke survivors who struggle with post-stroke commodities that adversely affecting their UE-related and daily functional skills. Related studies have primarily investigated the effects of music therapy application, including TIMP, as they related to improving impaired UE functions in stroke patients suffering from hemiparesis only. The findings of this study support the likelihood that TIMP intervention may also provide therapeutic benefits to stroke survivors who concurrently demonstrate both IMA and hemiparesis, thus enriching the literatures with new information on the consequences of stroke, and providing essential findings germane to future research.

In addition to providing new data on stroke-related sequelae, the study included IMA patients possessing relatively diverse functional abilities. In other words, the study intervention incorporated IMA patients with more severe motor deficiencies as well as those with greater functional capabilities. UE training (e.g., Constraint-Induced Movement Therapy) research has traditionally been grounded in initially investigating treatment effects in stroke patients who present mild to moderate impairment (Taub et al., 1999) and who are known to be good predictors of motor outcome and recovery following stroke (Wolf et al., 2006). In real-life practice, however, clinical practitioners commonly treat post-stroke patients possessing varying functional abilities, including individuals suffering persistent impairments such as IMA. In consideration of the need for efficacious treatment, including regimens applicable to patients with limited functions, the application of appropriate training for all functional levels of stroke survivors is essential to optimizing their quality of life (Langhammer & Lindmark, 2012). In this sense, the present study, as an initiatory attempt, provides some useful information and essential findings that may be built upon and compared to those arising from future investigations.

The study also offers some implications for clinical practice, as it may raise awareness of post-stroke comorbidity disorders such as IMA among patients, family members, and therapy-related allied health professionals. All stroke patients who participated in the screening test for inclusion eligibility, including the seven participants eventually chosen for the study, reported that they were neither diagnosed with nor informed about their IMA. During the study period, participants, family members and caregivers received information about IMA from the researcher, and actively observed and engaged in the intervention. Several family members and social worker reported that they had learned specific concepts and strategies, and asked for related materials that they could continue to apply in their home setting (e.g., sheet music for keyboard playing). Researchers have already pointed to the apparent need for efficacious treatment and proper assessment for IMA patients in current practice (Dovern et al., 2012; West et al., 2008). This is a particularly relevant observation, considering that practitioners working with stroke survivors should become proficient in addressing post-stroke comorbidities in order to assuage any disadvantages arising from clinical functional gains attributable to unfamiliarity or delay in diagnosis/identification and appropriate treatment. Ideally, the study's findings should inspire music therapy practitioners to give deeper consideration to practical areas for improvement, including the identification of essential factors enhancing the quality of treatment for stroke-related comorbidities.

In terms of actual implementation, this study offers suggestions for clinical music therapy application that might encourage beneficial treatment effects. The study may be of particular interest to music therapists by suggesting a feasible and executable treatment plan and efforts to be implemented in practice. Music therapists could thus readily acquire knowledge about potential treatment plans and add their own insights from the experience in order to deliver optimal treatment care. Furthermore, it would be of great benefit to patients if the treatment efforts could be transferred to natural contexts outside of therapy settings, such as home or community settings.

Limitations

The current study is clearly not without its limitations. In particular, the small sample size limited the study's generalizability of findings. Given the barriers to recruiting participants who met the specific inclusion criteria and were able to accommodate the study requirements into their schedules, it was not feasible to increase the sample size. Consequently, a cautious interpretation of findings, particularly for statistical analyses, is compulsory.

The present study targeted chronic participants (i.e., more than 6-month post stroke prior to study participation) commonly characterized by the absence of spontaneous recovery, and included two evaluations prior to the intervention period in order to verify a stable baseline.

However, there was no control group in the study, so a clear determination of whether the increased outcomes resulted from the intervention or from other potential factors such as maturation remained elusive.

Another limitation is related to the outcome measures. Particularly for ADL/IADL skills, this study only included the results of SIS testing, a measurement based on the participants' own perceptions. The SIS is a valid and reliable outcome measure with robust psychometric characteristics for evaluating the impact of stroke on daily living tasks (Duncan et al., 2003, 1999). Conceivably, the study could have gathered more concrete evidence of transferred UE functional gains in participants' lives had it included an outcome measure that directly assessed ADL/IADL tasks conducted by a trained evaluator, in addition to those obtained from self-measurement. In addition, a training effect could account for the UE improvements observed in the study, as all UE functional measures were repeated four times across the study timeline.

While the results of TIMP intervention support the potential for promising therapeutic outcomes, the study was unable to determine how specific factors of the therapeutic function of music, such as role of musical elements (e.g., rhythm, melody), influence therapeutic potential. Also, unclear is the degree to which application details (e.g., level/difficulty of drum vs. keyboard playing or adaptation) might affect optimal outcomes. In addition, the fidelity checklist used in the study comprised a gross measure by listing questions eliciting a yes or no response. Accordingly, more detailed findings pertaining to accuracy and consistency in implementing the intervention could not be thoroughly determined.

Suggestions for Future Research

The findings in the study support future exploration of treatment for stroke-related commodities. While the study results support TIMP's emerging efficacy, future studies should incorporate other research design features for strong efficacy, including a larger sample size, a control group, and a comparison group (e.g., stroke participants without IMA or other comparable treatment approaches). Regarding function-related considerations, homogeneity sampling would help in the planning of efficient intervention strategies and the selection of a functionally appropriate measurement tool, thus leading to more explicit treatment effects. In terms of the TIMP intervention, future studies should continue exploring specific intervention factors such as intervention dosage (i.e., the amount of intervention delivered), frequency, duration, intervention type (e.g., individual vs group) or settings (e.g., home vs clinic), thus allowing identification of clearer and optimized treatment guidelines when developing the intervention. These added considerations would likely facilitate more successful implementation and outcomes of the TIMP intervention. In addition, given the promising findings for patients with post-stroke IMA, further investigations could examine the potential efficacy of TIMP intervention for comorbid IMA as it relates to other neurologic disorders, such as in IMA patients with Alzheimer's, or other populations that may benefit from enhanced therapeutic regimens. Finally, future feasibility studies are warranted to explore music's therapeutic influence on apraxic-related deficiencies such as arm and hand gesture impairments in order to develop applicable therapeutic regimens that fully incorporate the rehabilitative function of musical stimulus.

Conclusions

While the therapeutic promise of TIMP intervention in stroke rehabilitation has been previously studied, little research has been dedicated to parsing the implications of stroke-related comorbidity in the music therapy literature. The present study examined the potential of Therapeutic Instrumental Music Performance (TIMP) intervention to improve Upper Extremity

(UE) functions in patients suffering from paresis and Ideomotor Apraxia (IMA) following a stroke. The results support TIMP's emerging efficacy in improving gross and fine motor skills as well as ADL skills in stroke survivors − even amid persistent IMA − with such improvements being sustained for 3 weeks post-intervention. All participants expressed high satisfaction about the intervention experience and indicated a strong desire to continue the program and recommend it to others.

This study represents an initial examination of the effects of TIMP intervention on the functional UE performance of IMA patients in stroke rehabilitation. It is hoped that music therapists will acquire valuable information from this study about stroke comorbidity care, especially as it relates to direct applicability in the work of current practitioners and future developments of research in their field. Researchers and practitioners alike must continue to develop efficient therapeutic strategies to facilitate functional independence for patients confronting physiological, psychological and social barriers to efficacious rehabilitation. The findings of the current study have considerable potential to generate such innovative treatments aimed at optimizing the physical rehabilitation of stroke survivors and improving their quality of life.

REFERENCES

Alexander, M., Baker, E., Naeser, A., Kaplan, E., & Palumbo, C. (1992). Neuropsychological and neuroanatomical dimensions of ideomotor apraxia. *Brain, 115*(Pt1), 87-107.

Altenmuller, E, Marco-Pallares, J., Munte, T. F., & Schneider, S. (2009). Neural reorganization underlies improvement in stroke-induced motor dysfunction by music-supported therapy. *Annals of the New York Academy of Sciences, 1169*, 395-405.

Altenmuller, E., & Schlaug, G. (2013). Neurologic music therapy: The beneficial effects of music making on neurorehabilitation. *Acoustical Science and Technology, 34*(1), 5-12.

Amengual, J. L., Rojo, N., Veciana de las Heras, M., Marco-Pallares, J., Grau-Sanchez, J., & Schneider, S., . . . Rodriquez-Fornells, A. (2013). Sensorimotor plasticity after music-supported therapy in chronic stroke patients revealed by transcranial magnetic stimulation. *PLos One, 8*(4), e61883, doi:10.1371/journal.pone.0061883

Bangert, M., & Altenmuller, E. (2003). Mapping perception to action in piano practice: A longitudinal DC-EEG-study. *BioMedCentral Neuroscience*, *4*, 25-36.

Bangert, M., Peschel, T., Schlaug, G, Rotte, M, Drescher, D., Hinriches, H., . . . Altenmuller, E. (2006). Shared networks for auditory and motor processing in professional pianists: Evidence from fMRI conjunction. *Neuroimage*, *30*, 917-926.

Basso, A., & Capitani, E. (1985). Spared musical abilities in a conductor with global aphasia and ideomotor apraxia. *Journal of Neurology, Neurosurgery & Psychiatry, 48*(5), 407-412.

Basso, A., Capitani, E., Della Sala, S., Laiacona, M., & Spinnler, H. (1987). Recovery from ideomotor apraxia. A study on acute stroke patients. *Brain, 110*, 747-760.

Bengtsson, S. L., Ullen, F., Ehrsson, H. H., Hashimoto, T., Kito, T., Naito, E., . . . Sadato, N. (2009). Listening to rhythms activates motor and premotor cortices. *Cortex, 45*(1), 62-71.

Bernardi, N. F., Aggujaro, A., Caimmi, M., Molteni, F., Maravita, A., & Luzzatti, C. (2009). A new approach to rhythm cueing of cognitive functions. *Annals of the New York Academy Sciences, 1169*(1), 417-421.

Bickerton, W. L., Riddoch, M. J., Samson, D., Balani, A. B., Mistry, B., & Humphreys, G. W. (2012). Systematic assessment of apraxia and functional predictions from the Birmingham cognitive screen. *Journal of Neurology, Neurosurgery & Psychiatry, 83*(5), 513-521.

Bienkiewicz, M. M. N., Brandi, M-L., Goldenberg, G., Hughes, C. M. L., & Hermsdorfer, J. (2014). The tool in the brain: Apraxia in ADL. Behavioral and neurological correlates of apraxia in daily living. *Frontiers in Psychology, 5*(353). doi:10.3389/fpsyg.2014.00353

Binkofski, F., & Buxbaum, L. J. (2013). Two actions systems in the human brain. *Brain and Language, 127*(2), 222-229.

Bjorneby, E. R., & Reinvang, I. R. (1985). Acquiring and maintaining self-care skills after stroke: The predictive value of apraxia. *Scandinavian Journal of Rehabilitation Medicine, 17*, 75-80.

Bolognini, N., Convento, S., Banco, E., Mattioli, F., Tesio, L., & Vallar, G. (2015). Improving ideomotor apraxia by electrical stimulation of the left posterior parietal cortex. *Brain, 138*, 428-439.

Brodmann, K. (2006). *Brodmann's localisation in the cerebral cortex: The principle of comparative localization in the cerebral cortex based on cytoarchitectonics; translated and edited by Garey, L.* New York, NY: Springer.

Buonomano, D. V., & Merzenich, M. M. (1998). Cortical plasticity: From synapses to maps. *Annual Review of Neuroscience, 21*, 149-186.

Butler, J. (2000). Rehabilitation of severe ideomotor apraxia using sensory simulation strategies: A single-case experimental design study. *British Journal of Occupational Therapy, 63*, 319-328.

Buxbaum, L. J. (2001). Ideomotor apraxia: A call to action. *Neurocase, 7*, 445-458.

Buxbaum, L. J., Giovanetti T., & Libon, D. (2000). The role of dynamic body schema in praxis: Evidence from primary progressive apraxia. *Brain and Cognition, 44*, 166-191.

Buxbaum, L. J., Halaland, K. Y., Hallett, M., Wheaton, L., Heilman, K. M., Rodriquez, A., & Rothi, L. J. G. (2008). Treatment of limb apraxia: Moving forward to improved action. *American Journal of Physical Medicine and Rehabilitation, 87*, 149-161.

Buxbaum, L. J., Johnson-Frey, S. H., & Bartlett-Williams, M. (2005). Deficient internal models for planning hand object interactions in apraxia. *Neuropsychologia, 43*, 917-929.

Buxbaum, L. J., Kyle, K. M., Grossman, M., & Coslett, H. B. (2007). Left inferior parietal representations for skilled hand-object interactions: Evidence from stroke and corticobasal degeneration. *Cortex, 43*, 411-423.

Buxbaum, L. J., Kyle, K. M., & Menon, R. (2005). On beyond mirror neurons: Internal representations subserving imitation and recognition of skilled object-related in humans. *Cognitive Brain Research, 25*, 226-239.

Buxbaum, L. J., Shapiro, A. D., & Coslett, H. B. (2014). Critical brain regions for tool-related and imitative actions: A componential analysis. *Brain, 137*, 1971-1985.

Buxbaum, L. J., Sirigu, A., Schwartz, M. F., & Klatzky, R. (2003). Cognitive representations of hand posture in ideomotor apraxia. *Neurospychologia, 41*, 1091-1113.

Cantagallo, A., Maini, M., & Rumiati, R. I. (2012). The cognitive rehabilitation of limb apraxia in patients with stroke. *Neuropsychological Rehabilitation, 22*(3), 473-488.

Carod-Artal, F. J., Coral, L. F., Trizotto, D. S., & Moreira, C. M. (2009). Self- and Proxi- report agreement on the Stroke Impact Scale. *Stroke, 40,* 3308- 3314.

Chen, H., Chen, C. C., Hsueh, I., Huang, S., & Hsieh, C. (2009). Test-retest reproducibility and smallest real difference of 5 hand function tests in patients with stroke. *Neurorehabilitation and Neural Repair, 23*(5), 435-440.

Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008b). Listening to musical rhythms recruits motor regions of the brain. *Cerebral Cortex, 18*, 2844-2854.

Cicerone, K. D., Dahlberg, C., Malec, J. F., Langenbahn, D. M., Felicetti, T., Kneipp, S., . . . Catanese, J. (2005). Evidence-based cognitive rehabilitation: Updated review of the literature from 1998 through 2002. *Archives of Physical Medicine and Rehabilitation, 86*(8), 1681-1692.

Civelek, G. M., Atalay, A., & Turhan, N. (2015). Association of ideomotor apraxia with lesion site, etiology, neglect, and functional independence in patients with first ever stroke. *Topics in Stroke Rehabilitation, 22*(2), 94-101.

Clark, M. A., Merians, A, S., Kothari, A., Poizner, H., Macauley, B., Rothi, L. J. G., & Heilman, K. M. (1994). Spatial planning deficits in limb apraxia. *Brain, 117*(Pt 5), 1093-1106.

Convento, S., Bolognini, N., Fusaro, M., Lollo, F., & Valla, G. (2014). Neuromodulation of parietal and motor activity affects motor planning and execution. *Cortex, 57*, 51-59.

De Renzi, E. (1989). Apraxia. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (pp. 245-263). Amsterdam: Elsevier.

De Renzi, E., Faglioni, P., & Sorgato, P. (1982). Modality-specific and supramodal mechanisms of apraxia. *Brain, 105*, 301-312.

De Renzi, E., Motti, F., & Nichelli, P. (1980). Imitating gestures: A quantitative approach to ideomotor apraxia. *Archives of Neurology, 37*, 6-10.

De Winter, J. C. (2013). Using the Student's t-test with extremely small sample size. *Practical Assessment, Research & Evaluation, 18*(10), 1-12.

Donkervoort, M., Dekker, J., & Deelman, B. (2006). The course of apraxia and ADL functioning in left hemisphere stroke patients treated in rehabilitation centres and nursing homes. *Clinical Rehabilitation, 20*, 1085-1093.

Donkervoort, M., Dekker, J., Stehmann-Saris, J. C., & Deelman, B. G. (2001). Efficacy of strategy training in left hemisphere stroke patients with apraxia: A randomized clinical trial. *Neuropsychological Rehabilitation, 11*(5), 549-566.

Donkervoort, M., Dekker, J., van den Ende, E., Stehmann-Saris, J. C., & Deelman, B. G. (2000). Prevalence of apraxia among patients with a first left hemisphere stroke in rehabilitation centres and nursing homes. *Clinical Rehabilitation, 14*, 130-136.

Dovern, A., Fink, G. R., & Weiss, P. H. (2012). Diagnosis and treatment of upper limb apraxia. *Journal of Neurology, 259*, 1269-1283.

Duncan. P. W., Bode, R. K., Lai, S. M., Peresa, S., & Glycine Antagonist in Neuroprotection Americas Investigators. (2003). Rasch analysis of a new stroke-specific outcome scale: The Stroke Impact Scale. *Archives of Physical Medicine and Rehabilitation, 84*(7), 950-963.

Duncan, P. W., Wallace, D., Lai, S. M., Johnson, D., Embretson, S., & Laster, L. J. (1999). The Stroke Impact Scale Version 2.0: Evaluation, of reliability, validity and sensitivity to change. *Stroke, 30*, 2131-2140.

Elliott, B. (1982). *Guide to the selection of musical instruments with respect to physical ability and disability*. Saint Louis, MO: MMB Music, Inc.

Felix II, R. A., Fridberger, A., Leijon, S., Berrebi, A. S., & Magnusson, A. K. (2011). Sound rhythms are encoded by postinhibitory rebound spiking in the superior paraolivary nucleus. *The Journal of Neuroscience, 31*, 12566-12578.

Flores-Mediana, Y., Chavez-Oliveros, M., Medina, L. D., Rodriquez-Agudelo, Y., & Solis-Vivanco, R. (2014). Brain lateralization of complex movement: Neuropsychological evidence from unilateral stroke. *Brain and Cognition, 84*(1), 164-169.

Fountana, A. P., Kilner, J. M., Rodriques, E. C., Joffily, M., Nighoghossian, N., Vargas, C. D., & Sirigu, A. (2012). Role of parietal cortex in predicting incoming actions. *Neuroimage, 59*, 556-564.

Foundas, A. L., Macauley, B. L., Raymer, A. M., Maher, L. M., Heilman, K. M., & Rothi, L. J. (1995). Ecological implications of limb apraxia: Evidence from mealtime behavior. *Journal of the International Neuropsychological Society, 1*, 62-66.

Fugl-Meyer, A. R., Jaasko, L., Leyman, I., Olsson, S., & Steglind, S. (1975). The post-stroke hemiplegic patient. 1. A method for evaluation of physical performance. *Scandinavian Journal of Rehabilitation Medicine*, *7*(1), 13-31.

Fujioka, T., Ween, J. E., Jamali, S. J., Stuss, D. T., & Ross, B. (2012). Changes in neuromagnetic beta-band oscillation after music-supported stroke rehabilitation. *Annals of the New York Academy of Sciences, 1252,* 294-304.

Galati, G., Committeri, G., Spitoni, G., Aprile, T., Di Russo, F., Pitzalis, S., & Pizzamigilo, L. (2008). A selective representation of the meaning of actions in the auditory mirror system. *Neuroimage, 40*(3), 1274-1286.

Gazzola, V., Aziz-Zadeh, L., & Keysers, C. (2006). Empathy and the somatotopic auditory mirror systems in humans. *Current Biology, 16*(18), 1824-1829.

Gebruers, N., Truijen, S., Engelborghs, S., & De Deyn, P. P. (2014). Prediction of upper limb recovery, general disability and rehabilitation status by activity measurements assessed by accelerometers of the Fugl-Meyer score in acute stroke. *American Journal of Physical Medicine and Rehabilitation, 93*(3) 245-252.

Geschwind, N. (1965). Disconnection syndromes in animals and man. *Brain, 88*, 237-294, 585-644.

Gladstone, D. J., Danells, C. J., & Black, S. E. (2002). The Fugl-Meyer Assessment of motor recovery after stroke: A critical review of its measurement properties. *Neurorehabillitaion and Neural Repair, 16*(3), 232-240.

Go, A. S., Mozaffarian, D., Roger, V. L., Benjamin, E. J., Berry, J. D., Blaha, M. J., . . . Turner, M. B.: American Heart Association Statistics Committee and Stroke Statistics Subcommittee. (2014). Heart disease and stroke statistics---2014 update: A report from the American Heart Association. *Circulation, 129*, e2-e182.

Goldenberg, G. (1995). Imitating gestures and manipulating a manikin: The representation of the human body in ideomotor apraxia. *Neuropsychologia, 33*(1), 63-72.

Goldenberg, G. (2001). Imitation and matching of hand and finger postures. *Neuroimage, 14*, S132-S136.

Goldenberg, G. (2003). Apraxia and beyond: Life and work of Hugo Liepmann. *Cortex, 39*(3), 509-524.

Goldenberg, G. (2009). Apraxia and the parietal lobes. *Neuropsychologia, 47*, 1449-1459.

Goldenberg, G. (2014). Apraxia: The cognitive side of motor control. *Cortex, 57*, 270-274.

Goldenberg, G., Daumuller, M., & Hangmann, S. (2001). Assessment and therapy of complex activities of daily living in apraxia. *Neuropsychological Rehabilitation, 11*, 147-169.

Goldenberg, G., & Hangmann, S. (1997). The meaning of meaningless gestures: A study of visuo-immitative apraxia. *Neuropsychologia, 35*(3), 333-341.

Goldenberg, G., & Hangman, S. (1998a). Therapy of activities of daily living in patients with apraxia. *Neuropsychological Rehabilitation, 8*, 123-141.

Goldenberg, G., & Hangman, S. (1998b). Tool use and mechanical problem solving in apraxia. *Neuropsychologia, 36*, 581-589.

Goldenberg, G., & Karnath, H. O. (2006). The neural basis of imitation is body part specific. *Journal of Neuroscience, 26*(23), 6282-6287.

Goldenberg, G., & Spatt, J. (2009). The neural basis of tool use. *Brain, 132*, 1645-1655.

Grau-Sanchez, J., Amengual, J. L., Rojo, N., Veciana de las Heras, M., Montero, J., Rubio, F., . . . Rodriquez-Fornells, A. (2013). Plasticity in the sensorimotor cortex induce by music-supported therapy in stroke patients: A TMS study. *Frontiers in Human Neuroscience, 7*(494), 1-11.

Guesgens, C. A. V., van Heugten, C. M., Cooijmans, J. P. J., Jolles, J., & van den Heuvel, W. J. A. (2007). Transfer effects of a cognitive strategy training for stroke patients with apraxia. *Journal of Clinical Experimental Neuropsychology, 29*(8), 831-841.

Guesgens, C., van Heugten, C., Donkervoort, M., van den Ende, E., Jolles, J., & van den Heuvel, W. (2006). Transfer of training effects in stroke patients with apraxia: An exploratory study. *Neuropsychological Rehabilitation, 16*(2), 213-219.

Haaland, K. Y., Harrington, D. L., & Knight, R. T. (1999). Spatial deficits in ideomotor limb apraxia: A kinematic analysis of aiming movements. *Brain, 122*, 1169-1182.

Haaland, K. Y., Harrington, D. L., & Knight, R. T. (2000). Neural representations of skilled movement. *Brain, 123*, 2306-2313.

Halsband, U., Ito, N., Tanji, J., & Freund, H. J. (1993). The role of premotor cortex and the supplementary motor area in the temporal control of movement in man. *Brain, 116*(Pt1), 243-266.

Halsband, U., Schmitt, J., Weyers, M., Binkofski, F., Grutzner, G., & Freund, H-J. (2001). Recognition and imitation of pantomimed motor acts after unilateral parietal and premotor lesions: A perspective on apraxia. *Neuropsychologia, 39*, 200-216.

Halwani, G. F., Loui, P., Ruber, T., & Schlaug, G. (2011). Effects of practice and experience on the arcuate fasciculus: Comparing signers, instrumentalists, and non-musicians. *Frontiers in Psychology, 2*(156). doi:10.3389/fpsyg.2011.00156

Hanna-Pladdy, B., Daniels, S. K., Fieselman, M. A., Thompson, K., Vasterling, J. J., Heilman, K. M., & Foundas, A. L. (2001). Praxis lateralization: Errors in right and left hemisphere stroke. *Cortex, 37*, 219-230.

Hanna-Pladdy, B., Heilman, K. M., & Foundas, A. L. (2001). Cortical and subcortical contributions to ideomotor apraxia: Analysis of task demands and error types. *Brain. 124*, 2513-2527.

Hanna-Pladdy, B., Heilman, K. M., & Foundas, A. L. (2003). Ecological implications of ideomotor apraxia: Evidence from physical activities of daily living. *Neurology 60*, 487-490.

Harrington, D. L., Haaland, K. Y., & Knight, R. T. (1998). Cortical networks underlying mechanisms of time perception. The *Journal of Neurosciences, 18*(3), 1085-1095.

Hatem, S. M., Saussez, G., della Faille, M., Prist, V., Zhang, X., Dispa, D., & Bleyenheuft, Y. (2016). Rehabilitation of motor function after stroke: A multiple systematic review focused on techniques to stimulate upper extremity recovery. *Frontiers in Human Neuroscience, 10*(442).

Heilman, K. M., & Rothi, L. J. G. (2003). Apraxia. In K. Heilman, K. & E. Valenstein (Eds.), *Clinical Neuropsychology* (pp. 215-235). New York: Oxford University Press.

Heilman, K. M., Rothi, L. J. G., Mack, L., Feinberg, T., & Watson, R. T. (1986). Apaxia after a superior parietal lesion. *Cortex, 22*(1), 141-50.

Heilman, K. M., Rothi, L. J. G., & Valenstein, E. (1982). Two forms of ideomotor apraxia. *Neurology, 32*, 342-346.

Hendricks, H. T., Limbeek, J., Geurts, A. C., & Zwarts, M. J. (2002). Motor recovery after stroke: A systematic review of the literature. *Archives Physical Medicine and Rehabilitation, 83,* 1629-1637.

Hermsdorfer, J., Goldenberg, G., Wachsmuth, C., Conrad, B., Ceballos-Baumann, A. O., Bartenstein, P., . . . Boecker, H. (2001). Cortical correlates of gesture processing: Clues to the cerebral mechanisms underlying apraxia during the imitation of meaningless gestures. *Neuroimage, 14*, 149-161.

Hermsdorfer, J., Hentze, S., & Goldenberg, G. (2006). Spatial and kinematic features of apraxic movement depend on the mode of execution. *Neuropsychologia, 44*, 1642-1652.

Hermsdorfer, J., Mai, N., Spatt, J., Marquardt, C., Veltkamp, R., & Goldenberg, G. (1996). Kinematic analysis of movement imitation in apraxia, *Brain, 119*(Pt 5), 1575-1586.

Hildebrand, M. W., Host, H. H., Binder, E. F., Carpenter, B., Freedland, K. E., Morrow-Howell, N., . . . Lenze, E. J. (2012). Measuring treatment fidelity in a rehabilitation intervention study. *American Journal of Physical Medicine and Rehabilitation, 91*(8), 715-724. doi:10.1097/PHM.0b013e31824ad462

Hodges, J. R., Spatt, J., & Patterson, K. (1999). What and how: Evidence for the dissociation of object knowledge and mechanical problem-solving skills in the human brain. *Proceedings of the National Academy of Sciences of the United States of America, 96*(16), 9444-9448.

Homberg, V. (2013). Neurorehabilitation approaches to facilitate motor recovery. *Handbook of Clinical Neurology, 110*, 161-173.

Hsieh, Y.W., Wu, C. Y., Lin, K. C., Chang, Y. F., Chen, C. L., & Liu, J. S. (2009). Responsiveness and validity of three outcome measures of motor function after stroke rehabilitation. *Stroke, 40*(4), 1386-1391.

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical training shapes structural brain development. *The Journal of Neuroscience, 29*(10), 3019-3025.

Ietswaart, M., Carey, D. P., & Della Sala, S. (2006). Tapping, grasping, and aiming in ideomotor apraxia. *Neuropsychologia, 44*(7), 1175-1184.

Jamali, S., Fujioka, T., & Ross, B. (2014). Neuromagnetic beta and gamma oscillations in the somatosensory cortex after music training in healthy older adults and a chronic stroke patient. *Clinical Neurophysiology, 125*(6), 1213-1222.

Jeong, S. H., & Kim, M. T. (2007). Effects of a theory-driven music and movement program for stroke survivors in a community setting. *Applied Nursing Research, 20,* 125-131.

Jorgensen, H. S., Nakayama, H., Raaschou, H. O., & Olsen, T. S. (1999). Stroke. Neurologic and functional recovery the Copenhagen stroke study. *Physical Medicine and Rehabilitation Clinics of North America, 10*(4), 887-906.

Kaya, K., Unsal-Delialioglu, S., Kurt, M., Altinko, N., & Ozel, S. (2006). Evaluation of ideomotor apraxia in patients with stroke: A study of reliability and validity. *Journal of Rehabilitation Medicine, 38*, 108-112.

Kertesz, A. (1982). *The Western Aphasia Battery*. New York: Grune & Stratton.

Keysers, C., Kohler, E., Umilta, M. A., Nanetti, L., Fogassi, L., & Galleses, V. (2003). Audiovisual mirror neurons and action recognition. *Experimental Brain Research, 153*(4), 628-636.

Kohler, C., Keysers, C., Umilta, M. A., Fogassi, L., Gallese, V., & Rizzolatti, G. (2002). Hearing sounds, understanding action: Action representation in mirror neuron. *Science, 297*, 846-848.

Konoike, N., Kotozaki, Y., Miyachi, S., Miyauchi, C. M., Yomogida, Y., Akimoto, Y., . . . Nakamura, K. (2012). Rhythm information represented in the fronto-parieto-cerebellar motor system. *Neuroimage, 63*, 328-338.

Kwakkel, G., Kollen, B. J., & Wagenaar (1999). Therapy impact on functional recovery in stroke rehabilitation: A critical review of the literature. *Physiotherapy, 85*(7), 377-391.

Kwakkel, G., Veerbeek, J. M., van Wegen, E. E., & Wolf, S. L. (2015). Constraint-induced movement therapy after stroke. *The Lancet Neurology, 14*(2), 224-234.

Kwon, S., Duncan, P., Studenski, S., Perera, S., Lai, S. M., & Reker, D. (2006). Measuring stroke impact with SIS: Construct validity of SIS telephone administration. *Quality of Life Research, 15*, 367-376.

Lacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfuntion. *Nature Reviews Neurosciences, 7*, 942-951.

Lahav, A., Saltzman, E., & Schlaug, G. (2007). Action representation of sound: Audiomotor recognition network while listening to newly acquired actions. *The Journal of Neuroscience, 27*(2), 308-314.

Laimgruber, K., Goldenberg, G., & Hermsdorfer, J. (2005). Manual and hemispheric asymmetries in the execution of actual and pantomimed prehension. *Neuropsychologia, 43*(5), 682-692.

Langhammer, B., & Lindmark, B. (2012). Functional exercise and physical fitness post stroke: The importance of exercise maintenance for motor control and physical fitness after stroke. *Stroke Research and Treatment, 2012*, doi:10.1155/2012/864835

Langhorne, P, Bernhardt, J., & Kwakkel, G. (2011). Stroke Rehabilitation. *The Lancet, 377*(9778), 1693-1702.

Leiguarda, R. (2001). Limb apraxia: Cortical or subcortical. *Neuroimage, 14*, S137-S141.

Leiguarda, R. C., & Marsden, C. D. (2000). Limb apraxias: Higher order disorders of sensorimotor integration. *Brain, 123*, 860-879.

Leon, A. C., Davis, L. L., & Kraemer, H. C. (2011). The role and interpretation of pilot studies in clinical research. *Journal of Psychiatric Research, 45*(5), 626-629.

Liepmann, H. (1920). Apraxia. *Ergbn, Ges. Med. 1*, 516-543.

Lin, K., Chuang, L., Wu, C., Hsieh, Y., & Chang, W. (2010). Responsiveness and validity of three dexterous function measures in stroke rehabilitation. *Journal of Rehabilitation Research & Development, 47*(6), 563-572.

Lin, K., Fu, T., Wu, C., Hsieh, Y., Chen, C., & Lee, P. (2010). Psychometric comparisons of the Stroke Impact Scale 3.0 and Stroke-Specific Quality of Life Scale. *Quality of Life Research, 19*(3), 435-443.

Lin, K., Hsieh, Y., Wu, C., Chen, C., Jang, Y. J., & Liu, J. (2009). Minimal detectable change and clinically important difference of the Wolf Motor Function Test in stroke patients. *Neurorehabilitation and Neural Repair, 23*(5), 429-434.

Luft, A. R., McCombe-Waller, S., Whitall, J., Forrester, L. W., Macko, R., Sorkin, J. D., . . . Hanley, D. F. (2004). Repetitive bilateral arm training and motor cortex activation in chronic stroke. A randomized controlled trial. *Journal of American Medical Association*, *292*(15), 1853-1861.

Magee, W. L., Clark, I., Tamplin, J., & Bradt, J. (2017). Music intervention for acquired brain injury. Cochrane Database of Systematic Review 2017, Issue 1. Art. No.: CD006787. DOI: 10.1002/14651858. CO006787.pub3.

Magee, W. L., & Davidson, J. W. (2002). The effects of music therapy on mood states in neurological patients: A pilot study. *Journal of Music Therapy, 39*(1), 20-29.

Maher, L. M., & Ochipa, C. (1997). Management and treatment of limb apraxia. In L. Rothi & K. Heilman (Eds.), *Apraxia: The neuropsychology of action* (pp. 75-91). East Sussex, UK: Psychology Press.

Maher, L. M., Rothi, L., & Greenwald, M. (1991). Treatment of gesture impairment: A single case. *American Speech Hearing Association, 33*, 195.

Malcolm, M, P., Massie, C., & Thaut, M. (2009). Rhythmic auditory-motor entrainment improves hemiparetic arm kinematics during reaching movements: A pilot study. *Top Stroke Rehabilitation, 16*(1), 69-79.

Manuel, A. L., Radman, N., Mesot, D., Chouiter, L., Clarke, S., Annoni, J., & Lucas, S. (2012). Inter and intrahemispheric dissociations in ideomotor apraxia: A large-scale lesion-symptom mapping study in subacute brain-damaged patients. *Cerebral Cortex, 23*(12), 2781-2789.

Massie, C., Malcolm, M., Greene, D., & Thaut, M. H. (2009). Effects of constraint-induced therapy on kinematic outcomes and compensatory movement patterns: An exploratory study. *Archives of Physical Medicine and Rehabilitation, 90*(4), 571-579.

Mathiowetz, V., Volland, G., Kashman, N., & Weber, K. (1985). Adult norms for the Box and Block Test of manual dexterity. *American Journal of Occupational Therapy, 39*(6), 386-391.

McCombe Waller, S., Harris-Love, M., Liu, W., & Whitall, J. (2006). Temporal coordination of the arms during bilateral simultaneous and sequential movements in patients with chronic hemiparesis. *Experimental Brain Research, 168,* 450-454.

McCombe Waller, S., Liu, W., & Whitall, J. (2008). Temporal and spatial control following bilateral versus unilateral training. *Human Movement Science, 27*, 749-758.

McCombe Waller, S., & Whitall, J. (2008). Bilateral arm training: Why and who benefits? *Neurorehabilitation, 23*(1), 29-41.

Meister, I. G., Krings, T., Foltys, H., Boroojerdi, B., Muller, M., Topper, R., & Thron, A. (2004). Playing piano in the mind: An fMRI study on music imagery and performance in pianists. *Cognitive Brain Research, 19*, 219-228.

Mertel, K. (2014). Therapeutical instrumental music performance (TIMP). In M. Thaut & V. Hoemberg (Eds.). *Handbook of Neurologic Music Therapy* (pp.116-139). Oxford, United Kingdom: Oxford University Press.

Moll, J., de Oliverira-Souza, R., Passman, L. J., Cimini Cunha, F., Souza-Lima, F., & Andreiuolo, P. A. (2000). Functional MRI correlates of real and imagined tool-use pantomimes. *Neurology, 54*, 1331-1336.

Morris, D. M., Uswatte, G., Crago, J. E., Cook, E. W. 3rd, Taub, E. (2001). The reliability of the Wolf Motor Function Test for assessing upper extremity function after stroke. *Archives of Physical Medicine and Rehabilitation, 82*, 750-755.

Moumdjian, L., Sarkamo, T., Leone, C., Leman, M., & Feys, P. (2017). Effectiveness of music-based interventions on motricity or cognitive functioning in neurological populations: A systematic review. *European Journal of Physical and Rehabilitation Medicine*. 53(3), 466-482.

Mutha, P. K., Sainburg, R. L., & Haaland, K. Y. (2010). Coordination deficits in ideomotor apraxia during visually targeted reaching reflect impaired visuomotor transformations. *Neuropsychologia, 48*, 3855-3867.

Nayak, S., Wheeler, B, L., Shiflett, S. C., & Agostinelli, S. (2000). Effect of music therapy on mood and social interaction among individuals with acute traumatic brain injury and stroke. *Rehabilitation Psychology, 45*(3), 274-283.

Ochipa, C., Maher, L.M., & Rothi, L. J. G. (1995). Treatment of ideomotor apraxia. *Journal of Clinical Experimental Neuropsychology, 2*, 149.

Ochipa, C. & Rothi, L. J. G. (2000). Limb apraxia. *Seminars in Neurology, 20*(4), 471- 478.

Ochipa, C., Rothi, L. J. G., & Heilman, K. M. (1992). Conceptual apraxia in Alzheimer's disease. *Brain, 115*(Pt 4), 1061-1071.

Ochipa, C., Rothi, L. J. G., & Heilman, K. M. (1994). Conduction apraxia. *Journal of Neurology, Neurosurgery, and Psychiatry, 57*, 1241-1244.

Osiurak, F., Aubin, G., Allain, P., Jarry, C., Richard, I., & Le Gall, D. (2008). Object usage and object utilization: A single-case study. *Neurocase, 14*(2), 169-183.

Osiurak, F., Jarry, C., Allain, P., Aubin, G., Etcharry-Bouyx, F., Richard, I., . . . Le Gall, D. (2009). Unusual use of objects after unilateral brain damage: The technical reasoning model. *Cortex, 45*, 769-783.

Osiurak, F., Jarry, C., & Le Gall, D. (2011). Re-examining the gesture engram hypothesis: New perspectives on apraxia of tool use. *Neuropsychologia, 49*, 299-312.

Osiurak, F., Jarry, C., Lesourd, M., Baumard, J., & Le Gall, D. (2013). Mechanical problem-solving strategies in left-brain damaged patients and apraxia of tool use. *Neuropsychologia, 51*(10), 1964-1972.

Paltsev, Y. I., & Elner, A. M. (1967). Change in functional state of segmental apparatus of spinal cord under influences of sound stimuli and its role in voluntary movement. *Biophysics-USSR, 12*, 1219-1226.

Peigneux, P., Van der Linden, M., Garraux, G., Laureys, S., Degueldre, C., Aerts, J., . . . Salmon, E. (2004). Imaging a cognitive model of apraxia: The neural substrate of gesture-specific cognitive process. *Human Brain Mapping, 21*, 119-142.

Petreska, B., Adriani, M., Blanke, O., & Billard, A. G. (2007). Apraxia: A review. *Progress in Brain Research, 164*, 61-83.

Pilgrim, E., & Humphreys, G. W. (1994). Rehabilitation of a case of ideomotor apraxia In M. Riddoch & G. Humphreys (Eds.), *Cognitive Neuropsychology and Cognitive Rehabilitation* (pp. 271-285). Hove, UK: Lawrence Erlbaum.

Platz, T., Pinkowski, C., van Wijck, F., Kim, I. H., di Bella, P., & Johnson, G. (2005). Reliability and validity of arm function assessment with standardized guidelines for the Fugl-Meyer Test, Action Research Arm Test and Box and Block Test: A multicenter study. *Clinical Rehabilitation, 19*(4), 404-411.

Poizner, H., Clark, M. A., Merians, A. S., Macauley, B., Rothi, L. J. G., & Heilman, K. M. (1995). Joint coordination deficits in limb apraxia. *Brain, 118*, 227-242.

Poizner, H., Mack, L., Verfaellie, M, Rothi, L, J. G., & Heilman, K. M. (1990). Three dimensional computer graphic analysis of apraxia. Neural representations of learned movement. *Brain, 58*, 174-179.

Pollock, A., Farmer, S. E., Brady, M. C., Langhorne, P., Mead, G. E., Mehrholz., & van Wijck, F. (2013). Interventions for improving upper limb function after stroke. *Cochrane Database of Systematic Review, 11.* CD010820.

Power, E., Code, C., Croot, K., Sheard, C., & Rothi, L. J. G. (2009). Florida Apraxia Battery-Extended and Revised Sydney (FABERS): Design, description, and a healthy control sample. *Journal of Clinical and Experimental Neuropsychology, 8*, doi:10.1080/13803390902791646

Raghavan, P., Geller, D., Guerrero, N., Aluru, V., Eimicke, J. P., Ogedegbe, G., . . . Turry, A. (2016). Music upper limb therapy-integrated: An enriched collaborative approach for stroke rehabilitation. *Frontiers in Human Neuroscience, 10*, doi:10.3398/fnhum.2016.00498

Ramnani, N., & Passinghan, R. E. (2001). Changes in the human brain during rhythm learning. *Journal of Cognitive Neuroscience, 13*(7), 952-966.

Randerath, J., Goldenberg, G., Spijkers, W., Li, Y., & Hermsdorfer, J. (2010). Different left brain regions are essential for grasping a tool compared with its subsequent use. *Neuroimage, 53*, 171-180.

Rapcsak, S. Z., Ochipa, C., Beeson, P. M., & Rubens, A. B. (1993). Praxis and the right hemisphere. *Brain and Cognition, 23*, 181-202.

Raymer, A. M., Maher, L. M., Foundas, A. L., Heilman, K. M., & Rothi, L. J. (1997). The significance of body part as tool errors in limb apraxia. *Brain and Cognition, 34*, 287-292.

Ripolles, P., Rojo, N., Grau-Sanchez, J., Amengual, J. L., Camara, E., Marco-Pallares, J., . . . Rodriquez-Fornells, A. (2016). Music supported therapy promotes motor plasticity in individuals with chronic stroke. *Brain Imaging and Behavior, 10*, 1289-1307.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27,* 169-192.

Rizzolatti, G., & Luppino, G. (2001). The cortical motor system. *Neuron, 31*(6), 889-901.

Rizzolatti, G., Luppino, G., & Matelli, M. (1998). The organization of the cortical motor system: New concepts. *Electroencephalography and Clinical Neurophysiology, 106*, 283-296.

Rodriquez-Fornells, A., Rojo, N., Amengual, J. L., Ripolles, P., Altenmuller, E., & Munte, T. F. (2012). The involvement of audio-motor coupling in the music-supported therapy applied to stroke patients. *Annals of the New York Academy of Sciences, 1252,* 282-293.

Robb, S. L., Burns, D. S., & Carpenter, J. S. (2011). Reporting guidelines for music-based interventions. *Journal of Health Psychology, 16*, 342-393.

Rojo, N., Amengual, J., Juncadella, M., Rubio, F., Camara, E., Marco-Pallares, J., . . . Rodriquez-Fornells, A. (2011). Music-supported therapy induces plasticity in the sensorimotor cortex in chronic stroke: A single-case study using multimodal imaging (fMRI-TMS). *Brain Injury, 25*(7-8), 787-793.

Rossignol, S., & Melvill Jones, G. (1976). Audiospinal influences in man studied by the H-reflex and its possible role in rhythmic movement synchronized to sound. *Electroencephalography and Clinical Neurophysiology, 4*(1), 203-208.

Rothi, L. J. G., Ochipa, C., & Heilman, K. M. (1991). A cognitive neuropsychological model of limb praxis. *Cognitive Neuropsychology, 8*, 443-458.

Rothi, L. J. G., Raymer, A. M., & Heilman, K. M. (1997). Limb praxis assessment. In L. J. G. Rothi & K. M. Heilman (Eds.), *Apraxia: The Neuropsychology of Action. Brain Damage, Behavior, and Cognition Series* (pp. 61-73). Hove, UK: Psychology Press.

Roy, E. A. (1996). Hand preference, manual asymmetries, and limb apraxia. In D. Elliot, (Ed.), *Manual Asymmetries in Motor Control* (pp. 215-236). Boca Raton, FL: CR Press.

Roy, E. A., Heath, M., Westwood, D., Schweizer, T. A., Dixon, M. J., Black, S. E., . . . Square, P. A. (2000). Task demands and limb apraxia in stroke. *Brain and Cognition, 44*(2), 253-279.

Roy, E. A., & Square, P. A. (1985). Common considerations in the study of limb, verbal and oral apraxia. In E. Roy (Ed.), *Neuropsychological Studies of Apraxia and Related Disorders* (pp.111-161). Amsterdam: North-Holland.

Roy, E. A., & Square, P. A. (1994). Neuropsychology of movement sequencing disorders and apraxia. In *D.* Zaidel (Ed.), *Neuropsychology* (pp. 183-218). London: Academic Press.

Rushworth, M. F. S., Johansen-Berg, H., Gobel, S. M., & Devlin, J. T. (2003). The left parietal and premotor cortices: Motor attention and selection. *Neuroimage, 20,* S89-S100.

Rushworth, M. F. S., Krams, M., & Passingham. R. E. (2001). The attentional role of the left parietal cortex: The distinct lateralization and localization of motor attention in the human brain. *Journal of Cognitive Neuroscience, 13*(5), 698-710.

Rushworth, M. F. S. Nixon, P. D., Renowden, S., Wade, D. T., & Passingham, R. E. (1997). The left parietal cortex and motor attention. *Neuropsychologia, 35*(9), 1261-1273.

Rushworth, M. F. S., & Taylor, P. C. J. (2006). TMS in the parietal cortex: Updating representations for attention and action. *Neuropsychologia, 44*, 2700-2716.

Sackett, D. L., Rosenberg, W. M., Gray, J. A., Haynes, R. B., & Richardson, W. S. (1996). Evidence based medicine: What it is and what it isn't. *BMJ: British Medical Journal, 312(*7023), 71-72.

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience, 14*(2), 257-262.

Sanford, J., Moreland, J., Swanson, L. R., Stratford, P. W., & Gowland, C. (1993). Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. *Physical Therapy, 73*(7), 447-454.

Sarkamo, T., & Soto, D. (2012). Music listening after stroke: Beneficial effects and potential neural mechanisms. *Annals of the New York Academy of Sciences, 1252,* 266-281.

Sarkamo, T, Tervaniemi, M., Laitinen, S., Forsblom, A., Soinila, S., Mikkonen, M., . . . Hietanen, M. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain, 131*(3), 866-876.

Schaefer, R. S., Morcom, A. M., Roberts, N., & Overy, K. (2014). Moving to music: Effects of heard and imagined musical cues on movement-related brain activity. *Frontiers in Human Neuroscience, 8*(774), doi:10.3389/fnhum.2014.00774

Schneider, S., Munte, T., Rodriquez-Fornells, A., Sailer, M., & Altenmuller, E. (2010). Music-supported training is more efficient than functional motor training for recovery of fine motor skills in stroke patients. *Music Perception, 27*(4), 271- 280.

Schneider, S., Schonle, P. W., Altenmuller, E., & Munte, T. F. (2007). Using musical instruments to improve motor skill recovery following a stroke. *Journal of Neurology, 254*, 1339-1346.

Schnider, A., Hanlon, R. E., Alexander, D. N., & Benson, D. F. (1997). Ideomotor apraxia: Behavioral dimensions and neuroanatomical basis. *Brain and Language, 57*, 125-136.

Seger, C., Spering, B. J., Sares, A. G., Quraini, S. I., Alpeter, C., David, J., & Thaut, M. H. (2013). Corticotriatal contributions to musical expectancy perception. *Journal of Cognitive Neuroscience, 25*, 1062-1077.

Senesac, C. R., Davis, S., & Richards, L. (2010). Generalization of a modified form of repetitive rhythmic bilateral training in stroke. *Human Movement Science, 29*(1), 137-148.

Sirigu, A., Duhamel, J. R., Cohen, L, Pillon, B., Dubois, B., & Agid, Y. (1996). The mental representation of hand movements after parietal cortex damage. *Science, 273*(5281), 1564-1568.

Smania, N., Aglioti, S. M., Girardi, F., Tinazzi, M., Fiaschi, A., Cosentino., A., & Corato, E. (2006). Rehabilitation of limb apraxia improves daily life activities in patients with stroke. *Neurology, 67*, 2050-2052.

Smania, N., Girardi, F., Domenicalli, C., Lora, E., & Aglioti, S (2000). The rehabilitation of limb apraxia: A study in left-brain-damaged patients. *Archives of Physical Medicine and Rehabilitation, 81*, 379-388.

Spatt,J., Bak, T., Bozeat, S., Patterson, K., & Hodges, J. R. (2002). Apraxia, mechanical problem solving and semantic knowledge: Contributions to object usage in corticobasal degeneration. *Journal of Neurology, 249*, 601-608.

Stamenova, V., Roy, E. A., & Black, S. E. (2010). Association and dissociations of transitive and intransitive gestures in left and right hemisphere stroke patients. *Brain and Cognition, 72*(3), 483-490.

Street, A. J., Magee, W. L., Odell-Miller, H., Bateman, A., & Fachner, J. C. (2015). Home-based neurologic music therapy for upper limn rehabilitation with stroke patients at community rehabilitation stage- A feasibility study protocol. *Frontier in Human Neuroscience. 9*, 1-16.

Street, A. J., Magee, W. L., Bateman, A., Parker, M., Odell-Miller, H., & Fachner, J. C. (2018). Home-based neurologic music therapy for arm hemiparesis following stroke: Results from a pilot, feasibility randomized controlled trial. *Clinical Rehabilitation, 32*(1), 18-28.

Sunderland, A., & Shinner, C. (2007). Ideomotor apraxia and functional ability, *Cortex, 43*(3), 359-367.

Sunderland, A., Walker, C. M., & Walker, M. F. (2006). Action errors and dressing disability after stroke: An ecological approach to neuropsychological assessment and intervention. *Neuropsychological Rehabilitation, 16*(6), 666-683.

Sundet, K., Finset, A., & Reinvang, I. (1988). Neuropsychological predictors in stroke rehabilitation. *Journal of Clinical and Experimental Neuropsychology, 10*, 363-379.

Tramo, M. J. (2001). Biology and music: Music of the hemispheres. *Science, 291*(5501), 54-56.

Taub, E., Lum, P. S., Hardin, P., Mark, V. W., & Uswatte, G. (2005). AutoCITE: Automated delivery of CI therapy with reduced effort by therapists. *Stroke, 36*(6), 1301-1304.

Taub, E., Miller, N. E., Novack, T. A., Cook, E. W. 3rd., Fleming, W. C., Nepomuceno, C. S., . . . Crago, J. E. (1993). Technique to improve chronic motor deficit after stroke. *Archives of Physical Medicine and Rehabilitation, 74*(4), 347-354.

Taub, E., Uswatte, G., & Pidikiti, R. (1999). Constrain-induced movement therapy: A new family of techniques with broad application to physical rehabilitation: A clinical review. *Journal of Rehabilitation Research and Development, 36*(3), 237-251.

Tecchio, F., Salustri, C., Thaut, M. H., Pasqualetti, P., & Rossini, P. M. (2000). Conscious vs unconscious adaptation: A MEG study of cerebral responses to rhythmic auditory stimuli. *Experimental Brain Research, 135*(2), 222-230.

Thaut, M. H. (2003). Neural basis of rhythmic timing networks in the human brain. *Proceedings of the New York Academy of Sciences, 999*, 364-373.

Thaut, M. H. (2005). *Rhythm, music, and the brain: Scientific foundation and clinical applications*. New York, NY: Routledge.

Thaut, M. H. (2013). Entrainment and the motor system. *Music Therapy Perspectives, 31*(1), 31-34.

Thaut, M. H. (2015). The discovery of human auditory-motor entrainment and its role in the development of neurologic music therapy. *Progress in Brain Research, 217*, 253-266.

Thaut, M. H., Demartin, M., & Sanes, J. N. (2008). Brain networks for integrative rhythm formation. *PLoS One, 3*(5), e2312.

Thaut, M. H., & Kenyon, G. P. (2003). Rapid motor adaptations to subliminal frequency shifts during syncopated rhythmic sensorimotor synchronization. *Human Movement Science, 22*(3), 321-338.

Thaut, M. H., Kenyon, G. P., Hurt, C. P., McIntosh, G. C., & Hoemberg, V. (2002). Kinematic optimization of spaciotemporal pattern in paretic arm training with stroke patients. *Neuropsychologia, 40*, 1073-1081.

Thaut, M. H., & McIntosh, G. C. (2014). Neurologic music therapy in stroke rehabilitation. *Current Physical Medicine and Rehabilitation Reports, 2,* 106-113.

Thaut, M. H., McIntosh, G. C., & Hoemberg, V. (2015). Neurobiological foundations of neurologic music therapy: Rhythmic entrainment and the motor system. *Frontiers in Psychology, 5*(1185). doi:10.3389/fpsyg.2014.01185

Thaut, M. H., Schleiffers, S., & Davis, W. B. (1991). Analysis of EMG activity in biceps and triceps muscle in a gross motor task under the influence of auditory rhythm. *Journal of Music Therapy*, *28,* 64-88.

Thaut, M. H., Stephan, K. M., Wunderlich, G., Schicks, W., Tellmann, L., Herzog, H., . . . Homberg, V. (2009). Distinct cortico-cerebellar activations in rhythm auditory motor synchronization. *Cortex, 45*, 44-53.

Tickle-Degnen, L. (2013). Nuts and bots of conducting feasibility studies. *American Journal of Occupational Therapy, 67*(2), 171-176.

Tierney, A., & Kraus, N. (2013). The ability to move to a beat is linked to the consistency of neural responses to sound. *Journal of Neurosciences, 33*, 14981-14988.

Thompson-Butel, A. G., Lin, G., Shiner, C. T., & McNulty, P. A. (2015). Comparison of three tolls to measure improvements in upper-limb function with poststroke therapy. *Neurorehabilitation and Neural Repair, 29*(4), 341-348.

Tong, Y., Forreider, B., Sun, X., Geng, X., Zhang, W., Du, H., . . . Ding, Y. (2015). Music-supported therapy (MST) in improving post-stroke patients' upper-limb motor functional A randomized controlled pilot study. *Neurological Research, 37*(5), 434-440.

Unsal-Delialioglu, S., Kurt, M., Kaya, K., Culha, C., & Ozel, S. (2008). Effects of ideomotor apraxia on functional outcomes in patients with right hemiplegia. *International Journal of Rehabilitation Research, 31*, 177-180.

van Delden, A. E. Q., Peper, C. E., Beek, P J., & Kwakkel, G. (2012). Unilateral versus bilateral upper limb exercise therapy after stroke: A system review. *Journal of Rehabilitation Medicine, 44*, 106-117.

van Heugten, C. M. (2001). Rehabilitation and management of apraxia after stroke. *Reviews in Clinical Gerontology, 11*, 177-184.

van Heugten, C. M., Dekker, J., Deelman, B. G., Stehmann-Saris, J. C., & Kinebanian, A. (2000). Rehabilitation of stroke patients with apraxia: The role of additional cognitive and motor impairments. *Disability and Rehabilitation, 22*, 547-554.

van Heugten, C. M., Dekker, J., Deelman, B. G., van Dijk, A., Stehmann-Saris, J. C., & Kinebanian, A. (1998). Outcome of strategy training in stroke patients with apraxia: A phase II study. *Clinical Rehabilitation, 12*, 294-303.

van Vugt, F. T., Kafczyk, T., Kuhn, W., Rollnik, J. D., Tillmann, B., & Altenmuller, E. (2016). The role of auditory feedback in music-supported stroke rehabilitation: A single-blinded randomized controlled intervention. *Restorative Neurology and Neuroscience, 34*(2), 297-311.

van Vugt, F. T., Ritter, J., Rollnik, J. D., Altenmuller, E. (2014). Music-supported motor training after stroke reveals no superiority of synchronization in group therapy. *Frontiers in Human Neuroscience, 8*(315), 1-9.

Vanbellingen, T., Kersten, B., Van Hemelrijk, B., Van de Winckel, A., Bertschi, M., Muri, R., . . . Bohlhalter, S. (2010). Comprehensive assessment of gesture production: A new test of upper limb apraxia (TULIA). *European Journal of Neurology, 17*, 59-66.

Vanbellingen, T., Kersten, B., Van de Winckel, A., Bellion, M., Baronti, F., Muri, R., & Bohlhalter, S. (2011). A new bedside test of gesture in stroke: the apraxia screen of TULIA (AST). *Journal of Neurology, Neurosurgery and Psychiatry,* 82, 389-392.

VanWeelden, K., & Cevasco, A. M. (2007). Repertoire recommendations by music therapists for geriatric clients during singing activities. *Music Therapy Perspectives, 25*(1), 4-12.

Villeneuve, M., & Lamontagne, A. (2013). Playing piano can improve upper extremity function after stroke: Case studies. *Stroke Research and Treatment, 2013*, Article ID 159105, doi:10.1155/2013/159105

Villeneuve, M., Penhune, V., & Lamontagne, A. (2014). A piano training program to improve manual dexterity and upper extremity function in chronic stroke survivors. *Frontiers in Human Neuroscience, 8,* 662, doi:10.3389/fnhum.2014.00662

Velozo, C. A., & Woodbury, M. L. (2011). Translating measurement findings into rehabilitation practice: An example using Fugl-Meyer Assessment-upper extremity with patients following stroke. *Journal of Rehabilitation Research & Development, 48*(10), 1211-1222.

Walker, C. M., Sunderland, A., Sharma, J., & Walker, M. F. (2004). The impact of cognitive impairment on upper body dressing difficulties after stroke: A video analysis of patterns of recovery. *Journal of Neurology, Neurosurgery and Psychiatry, 75,* 43-48.

Warren, J. E., Sauter, D. A., Eisner, F., Wiland, J., Dresner, M. A., Wise, R. J., . . . Scott, S. K. (2006). Positive emotions preferentially engage an auditory-motor "mirror" system. *The Journal of Neuroscience, 26*(50), 13067-13075.

Watson, R. T., Fleet, W. S., Rothi, L. J. G., & Heilman, K. M. (1986). Apraxia and the supplementary motor area. *Archives of Neurology, 43*(8), 787-792.

Watson, R. T., & Heilman, K. M. (1983). Callosal apraxia. *Brain, 106*, 391-403.

Weiss, P. H., Rhbari, N. H., Hesse, M. D., & Fink, G. R. (2008). Deficient sequencing of pantomimes in apraxia. *Neurology, 70*(11), 834-840.

West, C., Bowen, A., Hesketh, A., & Vail, A. (2008). Interventions for motor apraxia following stroke. *Cochrane Database of Systematic Reviews, Issue 1*, CD004132.

Wheaton, L. A., & Hallett, M. (2007). Ideomotor apraxia: A review. *Journal of the Neurological Sciences, 260*, 1-10.

Whitall, J., McCombe Waller, S., Silver, K. H., & Macko, R. F. (2000). Repetitive bilateral arm training with rhythmic auditory cueing improves motor function in chronic hemiparetic stroke. *Stroke, 31*(10), 2390-2395.

Winters, C., van Wegen., Daffertshofer, A., & Kwakkel, G. (2014). Generalizability of the proportional recovery model for the upper extremity after an ischemic stroke. *Neurorehabilitation and Neural Repair, 29*(7), 614-622.

Wolf, S. L., Catlin, P. A., Ellis, M., Archer, A. L., Morgan, B., & Piacentino, A. (2001). Assessing Wolf Motor Function Test as outcome measure for research in patients after stroke. *Stroke, 32*, 1635-1639.

Wolf, S. L., Winstein, C. J., Miller, J. P., Taub, E., Uswatte, G., Morris, D., . . . Nicholas- Larsen, D.; Excite Investigators. (2006). Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: The EXCITE randomized clinical trial. *Journal of American Medical Association, 296*(17), 2095-2104.

Woodbury, M. L., Velozo, C. A., Richards, L. G., Duncan, P. W., Studenski, S., & Lai, S. M. (2008). Longitudinal stability of the Fugl-Meyer Assessment of the upper extremity. *Archives of Physical Medicine and Rehabilitation, 89*(8), 1563-1569.

Wu, A. J., Burgard, E., & Radel, J. (2014). Inpatient rehabilitation outcomes of patients with apraxia after stroke. *Top Stroke Rehabilitation, 21*(3), 211-219.

Wu, A. J., Radel, J., & Hanna-Pladdy, B. (2011). Improved function after combined physical and mental practice after stroke: A case of hemiparesis and apraxia. *American Journal of Occupational Therapy, 65*(2), 161-168.

Yoo, J. (2009). The role of therapeutic instrumental music performance in hemipareitc arm rehabilitation. *Music Therapy Perspectives, 27*(1), 16-24.

Yoo, J. (2015, November). *Upper extremity exercises with therapeutic instrumental music performance for activities of daily living in stroke rehabilitation: A protocol feasibility study*. Poster session presented at the Annual national conference of the American Music Therapy Association, Kansas City, Missouri.

Young, J. A., & Tolentino, M. (2009). Stroke evaluation and treatment. *Top Stroke Rehabilitation, 16*(6), 389-410.

Zadikoff, C., & Lang, A. E. (2005). Apraxia in movement disorders, *Brain, 128*, 1480-1497.

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: Auditory-motor interactions in music perception and production. *Nature Review Neuroscience, 8*, 547-558.

Zwinkels, A., Geusgens, C., van de Sande, P., & van Heugten, C. (2004). Assessment of aparaxia: Inter-rater reliability of a new apraxia test, association between apraxia and other cognitive deficits and prevalence of apraxia in a rehabilitation setting. *Clinical Rehabilitation, 18*, 819-827.

APPENDIX A

Recruitment Materials

Initial Contact Script

Hello (insert name),

My name is _______. I conducted a skilled movement study at the University of Kansas Medical Center that you participated in previously. I'm calling to see if you might be interested in participating in another study, which involves music therapy to help stroke patients with their daily living tasks. Do you have a few minutes to talk about this with me today?

If respondent says "no": Alright. Well, thank you for your time. I hope you have a great day.

If respondent says "it's not a good time to talk": Oh, I totally understand. Would there be a better time for me to call you later? (Reschedule time for phone call if needed).

If respondent says "yes": Great! This new doctoral research study is being conducted by a research team member, from the University of Kansas, whose name is ___________. It's a clinical study that focuses on using music therapy intervention to improve upper extremity functions in stroke patients who are affected by paresis and apraxia at the same time. Your participation would be completely voluntary. If you agree to participate, the researcher, who's a board certified music therapist, will guide you one-on-one through music therapy sessions, where you'll be asked to play some musical instruments in exercises aimed at improving your arm and hand functions. There will be nine sessions in total over a four to five week period, with each session lasting up to roughly one hour. There will also be four separate visits for evaluation sessions. This study will be held at the offices of the American Stroke Foundation.

In consideration of your travel costs as well as your time and effort, you would receive a gift certificate to a local store in the amount of up to (insert the amount) upon completing the study.

If you are interested in learning more about the study, I can get you in touch with Jeehyun, the principal researcher, who will be happy to discuss further details and answer any questions you may have. Would you like me to help you contact her for more information?

If respondent says, "yes" for further information: Thanks, (insert name). I really appreciate your time today and your interest in the study. Jeehyun will contact you to discuss additional information. If you have any questions or concerns before then, please don't hesitate to contact me at (insert phone number). I hope you have a great day.

If respondent says, "no": Alright. Well, thank you for your time and consideration today, (insert name). I hope you have a great day.

In-Person Recruitment Script

Hello (insert name),

My name is Jeehyun Yoo. I'm a music therapist and PhD candidate at the University of Kansas. I'm currently conducting my doctoral dissertation research and was wondering if you might be willing to participate. The study involves music therapy interventions to help stroke patients with their daily living tasks. Do you have a few minutes to talk about this with me today?

If respondent says "no": Alright. Well, thank you for your time. I hope you have a great day.

If respondent says "yes": Great! Let me tell you a little bit about the study then. This research focuses on using music therapy intervention to improve upper extremity functions in stroke patients who are affected simultaneously by paresis and apraxia. I'm recruiting five to 10 participants who meet these criteria, and participation is completely voluntary. If you're willing to participate, I would do a preliminary check of your motor functions and ask some questions to see if you meet the study's inclusion criteria. Does this sound like something you'd be interested in doing?

If respondent says "no": Alright. Thank you for your time. I hope you have a great day.

If respondent says, "yes": Thanks, (insert name). I really appreciate your interest in this study. (Then check upper extremity functions and ask related questions for confirming eligibility).

If respondent says, "yes" but is not eligible for the study: Thank you so much for your time, (insert name). This study is mainly for survivors who are suffering from _____ , and have difficulties with _______. After checking your status, it does not seem like you're suffering from ________, which is a prerequisite for participation in this study. I'm sorry, but your current UE function does not conform with this study's inclusion criteria. However, if future research possibilities arise for which you may be more suitable candidate, we will be sure to let you know. Thank you so much for your time and consideration today!

If respondent says, "yes" and meets study eligibility: Thank you so much for your time, (insert name). If you agree to participate, you'll receive nine music therapy sessions, which will be conducted one-on-one with me. At these sessions, I will guide you through arm and hand exercises by having you play some musical instruments, including drums, a keyboard, and other rhythmic instruments. Each of the sessions will take up to one hour. There will be a total of nine sessions and we'd be spreading those appointments out over a period of four to five weeks, depending on your schedule. There will also be four visits for evaluation sessions.

I'll be conducting the therapy sessions in a private room at the offices of the American Stroke Foundation. Also, in consideration of your time and effort, you'd receive a (insert the amount) gift certificate to a local store once you complete all of the steps in the study.

If you need some more time to consider participating, I can give you a couple days to think it over. If you choose to participate, we will need to schedule our first meeting, obviously, where we'd take care of some paperwork (including a written consent form) and conduct the first evaluation, which will take approximately one hour.

So would you be interested in participating in this study? And do you have any questions or concerns about the study, the scheduling, or anything else that I might help you with?
(Answer questions. Schedule a meeting if appropriate)

If respondent says, "yes" to participation and first meeting is scheduled: Thanks, (insert name). I really appreciate your time and consideration today. I'm looking forward to meeting you on (date) at (insert location). If you have any questions before then or need to change the schedule, please don't hesitate to contact me at (insert phone number). I hope you have a great day.

If respondent says, "I will need time to consider": Certainly! I can give you the next couple days to think it over. Thanks for your time today (insert name), and for considering participating in this study. Please let me know about your decision when you can, I'd really appreciate it. I hope you have a great day.

If respondent says, "no": Alright, well, thank you for your time and consideration today, (insert name). I hope you have a great day.

Phone Recruitment Script

Hello (insert name),

My name is ____________. I'm a music therapist and PhD candidate at the University of Kansas. I actually got your contact information from __________ at the University of Kansas Medical Center. You might be willing to participate in a study that I'm conducting, which involves music therapy to help stroke patients with their daily living tasks. Do you have a few minutes to talk about this with me today?

If respondent says "no": Alright. Well, thank you for your time. I hope you have a great day.

If respondent says "it's not a good time to talk": Oh, I totally understand. Would there be a better time for me to call you later? (Reschedule time for phone call if needed).

If respondent says "yes": Great! Let me tell you a little bit about the study then. It's my doctoral research study and it focuses on using music therapy intervention to improve upper extremity functions in stroke patients who are affected simultaneously by paresis and apraxia. So I'm recruiting five to 10 participants who meet these criteria, and participation is completely voluntary. If you agree to participate, you'll receive nine music therapy sessions, which will be conducted one-on-one with me. At these sessions, I will guide you through arm and hand exercises by having you play some musical instruments, including drums, a keyboard, and other rhythmic instruments. Each of the sessions will take up to one hour. There will a total of nine session and we'd spreading those appointments out over a period of four to five weeks, depending on your schedule. There will also be four visits for evaluation sessions.

I'll be conducting the therapy sessions in a private room at the offices of the American Stroke Foundation, located at (insert address). Also, in consideration of your travel costs as well as your time and effort, you'd receive a (insert the amount) gift certificate to a local store once you complete all of the steps in the study.

If you need some more time to consider participating, I can give you a couple days to think it over. If you choose to participate, we will need to schedule our first meeting, obviously, where we'd take care of some paperwork (including a written consent form) and conduct the first evaluation, which will take approximately one hour.

So would you be interested in participating in this study? And do you have any question or concerns about the study, the scheduling, or anything else that I might help you with?
(Answer questions. Schedule a meeting if appropriate)

If respondent says, "yes" to participation and first meeting is scheduled: Thanks, (insert name). I really appreciate your time and consideration today. I'm looking forward to meeting you on (date) at (insert location). If you have any questions before then or need to change the schedule, please don't hesitate to contact me at (insert phone number). I hope you have a great day.

If respondent says, "I will need time to consider": Certainly! I can give you the next couple days to think it over. Thanks for your time today (insert name), and for considering participating in this study. Please let me know about your decision when you can, I'd really appreciate it. I hope you have a great day.

If respondent says, "no": Alright. Well, thank you for your time and consideration today, (insert name). I hope you have a great day.

Recruitment Flyer

* Research Participants Needed*

Are you having difficulties using your upper extremities for daily life tasks?

Jeehyun Yoo, a PhD candidate at the University of Kansas is seeking her research participants for her dissertation study. The study examines the efficacy of **music therapy** in improving **upper extremity functions** in **stroke survivors suffering concurrently from paresis and apraxia**.

Music therapy, an innovative approach to stroke rehabilitation, utilizes musical experiences to achieve non-musical therapeutic goals. Numerous studies have attested to the promising results of this regimen, documenting how music therapy for motor functions can improve functional skills of the upper and lower extremities, such as arm reaching movements or walking.

To participate in this study you must:

- have had a stroke at least 6 months ago
- have weakness or paralysis in one arm/hand
- have the ability to move the more affected arm/hand without help from the less affected arm/hand
- have the ability to grip with the thumb and index finger of the more affected hand without help from the less affected arm/hand.
- have suffered apraxia
- be able to follow simple directions
- have no underlying medical conditions that prevent you from participating in 1-hour music therapy sessions

The participants will receive nine music therapy sessions involving the playing of musical instruments. These sessions are free of charge and will be conducted one-on-one with a board-certified music therapist. No previous musical experience is required.

If you are interested and would like more information,
please contact: Jeehyun Yoo, MM, MT-BC
Email: xxx-xxx-xxxx
Phone: xxx-xxx-xxxx

* Participants will also receive compensation of $150 upon completion of the nine sessions and evaluation.

Auditory Verbal Comprehension Test

Date _______________ Subject Initial ______________

Yes/No Questions

Explain to the patient that you are going to ask some questions and that the answers should be either "yes" or "no." The instructions should be repeated, if necessary during the test. Reinforce the patient when he or she gets into the set of answering as requested, but avoided nodding or commenting on specific items. If the patients self-corrects, the last answer is scored. If a patient gives an ambiguous or confabulatory repeat the instructions and the question and score accordingly. If the response is still ambiguous, score 0. Score 3 points for each correct answer.

	Verbal
1. Is Your Name Smith? ("no" should be correct)	
2. Is Your Name Brown? ("no" should be correct)	
3. Is Your Name (real name)?	
4. Do You Live in Toronto ("no" should be correct)	
5. Do You Live in (real residence)?	
6. Do You Live in Windsor? ("no" should be correct)	
7. Are You A Man/Woman? ("no" should be correct)	
8. Are You A Doctor? ("no" should be correct)	
9. Am I A Man/Woman? ("yes" should be correct)	
10. Are The Lights On This Room? ("yes" should be correct)	
11. Is The Door Closed? ("yes" should be correct)	
12. Is This A Hotel?	
13. Is This (real test location)?	
14. Are You Wearing Red Pajamas? ("no" should be correct)	
15. Will Paper Burn In Fire?	
16. Does March Come Before June?	
17. Do You Eat A Banana Before You Peel It?	
18. Does It Snow In July?	
19. Is A Horse Larger Than A Dog?	
20. Do You Cut The Grass A With An Ax?	

Maximum Score 60
Patient's Score ______

APPENDIX B

Informed Consent Form

RESEARCH CONSENT FORM
Therapeutic Instrumental Music Performance (TIMP)
to Improve Upper Extremity Function in
Ideomotor Apraxia Following Stroke

You are being asked to join a research study. You are being asked to take part in this study because you have had a stroke in the past. You do not have to participate in this research study. The main purpose of research is to create new knowledge for the benefit of future patients and society in general. Research studies may or may not benefit the people who participate.

Research is voluntary, and you may change your mind at any time. There will be no penalty to you if you decide not to participate, or if you start the study and decide to stop early. Either way, you can still get medical care and services at the institution.

This consent form explains what you have to do if you are in the study. It also describes the possible risks and benefits. Please read the form carefully and ask as many questions as you need to, before deciding about this research.

You can ask questions now or anytime during the study. The researchers will tell you if they receive any new information that might cause you to change your mind about participating. The study will take place at the office of the American Stroke Foundation with Dr. Cynthia Colwell, Director of Music Therapy, Music Education and Music Therapy at the School of Music, University of Kansas, as Principal Investigator, and Jeehyun Yoo, a doctoral student researcher of Music Education and Music Therapy at the School of Music, University of Kansas, as Co-Investigator. Roughly 10 people will be in the study from University of Kansas Medical Center (KUMC) and American Stroke Foundation.

BACKGROUND

Stroke can afflict its suffers with enduring functional limitations that can negatively impact the performance of daily activities. Music therapy, on the other hand, utilizes musical experiences to help patients achieve non-musical goals and improve their quality of life. Research has shown that music therapy, particularly Therapeutic Instrumental Music Performance (TIMP), can result in improved upper extremity (UE) functions (e.g., arm or hand) in stroke survivors. Numerous studies have examined stroke-induced paresis, yet research on stroke-related comorbid disorders remains limited, with relatively little consideration being given to the consequences of stroke. Ideomotor apraxia (IMA) is one such common post-stroke consequence that may hinder the purposeful actions and movements required for daily living tasks.

PURPOSE

The purpose of this study is to investigate whether music therapy can improve UE functions in post-stroke patients suffering concurrently from paresis and apraxia.

PROCEDURES
This study will include two stages: 1) music therapy intervention and 2) assessments.

1) Music therapy (MT) intervention will consist of a total of 9 individual sessions conducted over 4-5 weeks. Each session will involve a 1-hour MT session for each participant, provided by a co-investigator/board-certified music therapist. Each music therapy session will consist of a warm-up period, functional UE exercises for gross and fine motor skills, and a cool-down period.

1. Warm up: The interventionist will ask questions about your current status (e.g., feelings, physical issues, concerns, etc.) and loosen your muscles with simple stretching or neck rotation exercises.

2. Functional exercise for gross motor skills: You will be asked to exercise your arms by playing rhythmic instruments, namely a drum set with six drum pads. The six drum pads will be placed in different spatial positions horizontally and vertically. While in a seated position, you will then be asked to engage in arm and shoulder exercises by playing the drum pads situated at different target locations.

3. Functional exercise for fine motor skills: You will be asked to play a keyboard. Finger exercises will start with each individual finger, either playing a single note once or repetitively. This will be followed by exercises using several fingers to play several notes. After the finger exercises, you will be asked to play your choice of a simple children's song.

4. Cool-down: After UE training, the session will wrap up with a deep breathing exercise.

2) Assessments will be administered 4 times throughout the study; twice before the music therapy intervention period (i.e., pretests), once after completing the music therapy intervention (i.e., posttest) and once at the 3-week mark after the posttest (i.e., follow-up test). During the assessments, you will be asked to move or hold your arm(s) briefly in one of several positions, to use your arms and hands to complete several daily living tasks (e.g., picking up small objects, etc.), and to use your arm(s) to simulate using several different objects or tools. Each assessment session will take approximately 1 hour to complete.

RISKS
There are no anticipated risks for this study. It is possible that you may become tired from arm exercises during the 50-60 minute MT sessions. If this should happen, we will immediately halt the exercise to let you rest until you feel comfortable resuming the session. Following such an episode, we will discuss strategies to prevent the recurrence of such incident. There may be other risks of the study that are not yet known.

BENEFITS
You may or may not benefit from this study. The researcher hopes that the information from this research study will help to improve the rehabilitation of patients following stroke.

ALTERNATIVES
Since the research is testing the use of music, the only alterative to participating is to not participate. Participation in this study is voluntary. Deciding not to participate will have no effect on the care or services you receive at the University of Kansas Medical Center or American Stroke Foundation.

COSTS
There is no cost for participating in this study.

COMPENSATION TO SUBJECTS

Compensation will be rendered in the form of prepaid gift cards. You will receive a $20 gift card for completing visit 2 (pretest), an $80 gift card for completing visit 12 (posttest), and a $50 gift card upon completing visit 13 (follow-up test). Those who complete the entire study would thus be compensated up to a total amount of $150 (in gift cards). If your participation in this study ends early, you will be compensated only for the visits you have completed.

Study payments are taxable income. A Form 1099 will be sent to you and the Internal Revenue Service if your payments are $600 or more in a calendar year. The KUMC Research Institute will be given your name, address, social security number, and the title of this study in order to manage study payments.

IN THE EVENT OF INJURY

If you experience any harm or discomfort during this study, you should immediately contact Jeehyun Yoo at 785-840-6582. If Ms. Yoo is unavailable, another member of the research team will assist you in determining what type of treatment, if any, may be best for you at that time.

INSTITUTIONAL DISCLAIMER STATEMENT

If you think you have been harmed as a result of participating in research at the University of Kansas Medical Center (KUMC), you should contact the Director, Human Research Protection Program, Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160. Under certain conditions, Kansas state law or the Kansas Tort Claims Act may allow for payment to persons who are injured in research at KUMC.

CONFIDENTIALITY AND PRIVACY AUTHORIZATION

The researchers will protect your information, as required by law. Absolute confidentiality cannot be guaranteed because persons outside the study team may need to look at your study records. The researchers may publish the results of the study. If they do, your name will not be used in any publication or presentation about the study.

Your health information is protected by a federal privacy law called HIPAA. By signing this consent form, you are giving permission for KUMC to use and share your health information. If you decide not to sign the form, you cannot be in the study.

The researchers will only use and share information that is needed for the study. Your study-related health information (e.g., your name, age, diagnoses, etc.) will be used at KUMC by members of the research team, officials at KUMC who oversee research, including members of the KUMC Human Subjects Committee and other committees and offices that review and monitor research studies. To ensure confidentiality, all data collected on you (e.g., UE functional test results) will be assigned a code number. The list of participant names and code numbers will be stored in a locked filing cabinet by the principal investigator and kept separate from the raw data.

By signing this form, you are giving KUMC permission to share information about you with persons or groups at The University of Kansas-Lawrence campus. Your information will be share with Dr. Cynthia Colwell, members of the research team and U.S. agencies that oversee human research (if a study audit is performed). These persons or groups may make copies of study records for audit purposes. The purpose for using and sharing your information is to make sure the study is done properly.

Your permission to use and share your health information remains in effect until the study is complete and the results are analyzed. After that time, researchers will remove personal information from study records.

QUESTIONS

Before you sign this form, Jeehyun Yoo, Co-Investigator, or other members of the study team should answer all your questions. You can talk to the researchers if you have any more questions, suggestions, concerns or complaints after signing this form. If you have any questions about your rights as a research subject, or if you want to talk with someone who is not involved in the study, you may call the Human Subjects Committee at (913) 588-1240. You may also write the Human Subjects Committee at Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160.

SUBJECT RIGHTS AND WITHDRAWAL FROM THE STUDY

You may withdraw from the study at any time. Your decision to withdraw will not prevent you from getting treatment or services at KUMC or the American Stroke Foundation. The entire study may be discontinued for any reason without your consent by the investigator conducting the study.

You have the right to cancel your permission for researchers to use your health information. If you want to cancel your permission, please write to Dr. Cynthia Colwell, University of Kansas, 1530 Naismith Dr. #432, Murphy Hall, Lawrence, KS, 66045. If you cancel permission to use your health information, you will be withdrawn from the study. The research team will stop collecting any additional information about you. The research team may use and share information that was gathered before they received your cancellation.

CONSENT

Jeehyun Yoo or the research team has given you information about this research study. They have explained what will be done and how long it will take. They explained any inconvenience, discomfort or risks that may be experienced during this study.

By signing this form, you say that you freely and voluntarily consent to participate in this research study. You have read the information and had your questions answered.
You will be given a signed copy of the consent form to keep for your records.

____
Print Participant's Name

___________________________________ ____________________
Signature of Participant Date

____
Print Name of Person Obtaining Consent

___________________________________ ____________________
Signature of Person Obtaining Consent Date

APPENDIX C

Intervention Materials

Questionnaire for Song Preferences

Date_____________________ Name _____________________

Please circle your preferred songs from a song list.

Amazing Grace

Country Roads

Crawdad Song

Daisy Bell (Bicycle Built for Two)

Deep in the Heart of Texas

Don't Sit Under the Apple Tree

Down by the Riverside

Edelweiss

Five Foot Two, Eyes of Blue

Happy Birthday to You

Here Comes the Sun

Hey Good Lookin'

Home on the Range

I Can See Clearly Now

I've Been Working on the Railroad

Jambalaya

Jamaica Farewell

Let It Be

Let Me Call You Sweetheart

My Bonnie Lies Over the Ocean

My Favorite Things

My Wild Irish Rose

O Susanna

Oh What a Beautiful Morning

Que Sera Sera

She'll be Comin' Round the Mountain

Show Me the Way to Go Home

Side by Side

Sidewalks of New York

Springtime in the Rockies

Swing Low, Sweet Chariot

Take Me Out to the Ball Game

The Happy Wanderer

The Little Brown Jug

The Yellow Roses of Texas

This Land is Your Land

When Johnny Comes Marching Home

When the Saints Go Marching In

Yankee Doodle

Yellow Submarine

You Are my Sunshine

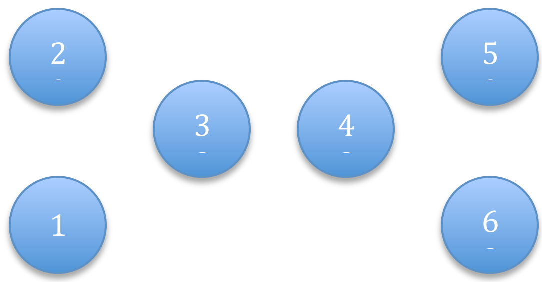
Your Cheating Heart

Write your favorite songs besides the list.

____

____

TIMP Intervention - Drum



Six drum pads were placed in a different height, drum 1 and 6 are at the lowest, drum 3 and 4 are at the medium high, and drum 2 and 5 are at the highest.

	Movement	Drum Pad Use	Sequence	Direction of Movement	UE Function
Unilateral	Forward	1	1-1-1, 2-2-2, 3-3-3,…		Shoulder flexion, elbow extension
	Vertical	2	1-2 (or 2-1) 5-6 (or 6-5)	Vertical up, down	Shoulder flexion/extension, elbow extension/flexion
	Lateral	2	3-4 (or 4-3) 2-5 (or 5-2) 1-6 (or 6-1)		Horizontal extension/flexion, elbow extension/flexion
	Diagonal	2	1-3, 1-4, 1-5 3-5, 4-5	Diagonal up/outward	Shoulder flexion, abduction, elbow extension
			6-4, 6-3, 6-2 4-2	Diagonal up/inward	Shoulder flexion, adduction elbow extension
Unilateral	Diagonal	2	2-4, 2-6	Diagonal down	Shoulder extension, abduction, elbow extension
			5-4, 5-3, 5-1 4-1, 3-1	Diagonal down	Shoulder extension, adduction, elbow extension
	Vertical +Lateral	3	1-2-5 1-6-5	Vertical up, Lateral right	Shoulder flexion, horizontal extension(abduction), elbow extension

	Movement	Drum Pad Use	Sequence	Direction of Movement	UE Function
(Unilateral continued)	Vertical +Lateral	3	6-5-2 6-1-2	Vertical up, Lateral left	Shoulder flexion, horizontal flexion(adduction), elbow extension
			2-1-6 2-5-6	Vertical down, Lateral right	Shoulder extension, horizontal abduction, elbow flexion
			5-6-1 5-2-1	Vertical down, Lateral left	Shoulder extension, horizontal adduction, elbow flexion
		4	1-2-5-6	Vertical up/down, Lateral right	Shoulder flexion/extension, horizontal abduction, elbow extension/flexion
			6-5-2-1	Vertical up/down, Lateral left	Shoulder flexion/extension, horizontal adduction, elbow extension/flexion
			1-6-5-2 6-1-2-5	Lateral right/left, Vertical up	Shoulder flexion, horizontal ab/adduction, elbow extension
			5-2-1-6	Lateral right/left, Vertical down	Shoulder extension, horizontal ab/adduction, elbow flexion
		5	1-2-5-6-1 6-5-2-1-6	Vertical up/down, Lateral right/left	Shoulder flexion/extension, horizontal ab/adduction, elbow extension/flexion
	Vertical+Diagonal	3	1-2-6	Vertical up, Diagonal outward	Shoulder flexion, abduction, elbow flexion/extension
			6-5-1	Vertical up, Diagonal inward	Shoulder flexion, adduction, elbow extension/flexion
			1-5-6	Diagonal outward, Vertical down	Shoulder abduction extension, elbow extension/flexion

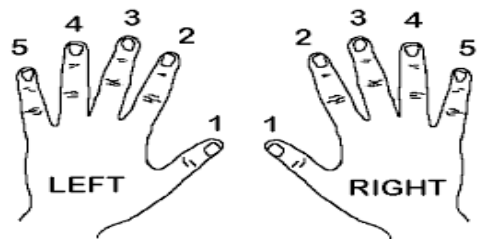
	Movement	Drum Pad Use	Sequence	Direction of Movement	UE Function
(Unilateral continued)	Vertical+Diagonal	3	6-2-1	Diagonal inward, Vertical down	Shoulder adduction. extension, elbow extension/flexion
		4	1-2-4(3)-6 2-4(3)-6-5	Vertical up, Diagonal outward	Shoulder flexion/extension, abduction, elbow flexion/extension
			6-5-3(4)-1 5-3(4)-1-2	Vertical up, Diagonal inward	Shoulder flexion/extension, adduction, elbow extension/flexion
			2-1-4(3)-5 1-4(3)-5-6	Vertical down, Diagonal outward	Shoulder extension/flexion, abduction, elbow extension/flexion
			5-6-3(4)-2 6-3(4)-2-1	Vertical down, Diagonal inward	Shoulder extension/flexion, adduction, extension, elbow flexion
	Lateral +Diagonal	3	3-4-5 or 1-3-4	Lateral right, Diagonal up	Shoulder abduction, flexion, elbow extension/flexion
			2-3-4 or 3-4-6	Lateral right, Diagonal down	Shoulder abduction, extension, elbow extension/flexion
			4-3-2 or 6-4-3	Lateral left, Diagonal up	Shoulder adduction, flexion, elbow extension/flexion
			5-4-3 or 4-3-1	Lateral left, Diagonal down	Shoulder adduction, extension, elbow extension/flexion
	Lateral + Diagonal	4	1-3-4-5	Lateral right, Diagonal up	Shoulder flexion, abduction, elbow extension
			2-3-4-6	Lateral right, Diagonal down	Shoulder extension, abduction, elbow flexion
			6-4-3-2	Lateral left, Diagonal up	Shoulder flexion, adduction, elbow extension

	Movement	Drum Pad Use	Sequence	Direction of Movement	UE Function
(Unilateral continued)	Lateral + Diagonal	4	5-4-3-1	Lateral left, Diagonal down	Shoulder extension, adduction, elbow flexion
			2-3-4-5 1-3-4-6	Diagonal up/down, Lateral right	Shoulder flexion/extension, abduction, elbow extension/flexion
			5-4-3-2 6-4-3-1	Diagonal up/down, Lateral left	Shoulder flexion/extension adduction, elbow extension/flexion
	Diagonal+Diagonal	3	1-3(4)-5	Diagonal right up	Shoulder abduction, flexion, elbow extension
			6-3(4)-2	Diagonal left up	Shoulder adduction, flexion, elbow extension
			2-4(3)-6	Diagonal right down	Shoulder abduction, extension, elbow flexion
			5-3(4)-1	Diagonal left down	Shoulder adduction, extension, elbow flexion
		4	1-3(4)-5-1 2-3(4)-6-2	Diagonal right up/down	Shoulder ab/adduction, flexion/extension, elbow extension/flexion
			6-4(3)-2-6 5-4(3)-1-5	Diagonal left up/down	Shoulder ab/adduction, flexion/extension, elbow extension/flexion
	Diagonal+Diagonal	4	1-4-2-6 6-3-5-1 1-5-3-6 6-2-4-1	Diagonal right/left up/down	Shoulder ab/adduction, flexion/extension, elbow extension/flexion
	Vertical, Lateral, Diagonal	4~6	1, 2, 3, 4, 5, 6 Random mix	Vertical up/down, Lateral right/left, Diagonal out/inward	Shoulder extension/flexion, ab/adduction, elbow extension/flexion

	Movement	Drum Pad Use	Sequence	Direction of Movement	UE Function
Bilateral	Vertical	2	1-2(L) 5-6(R) 2-1(L) 6-5(R)	Vertical up/down	Shoulder extension/flexion
	Diagonal	2	3-2(L) 4-5(R) 3-1(L) 4-6(R)	Diagonal up/down	Shoulder ab/adduction, elbow extention/flexion
	Vertical+Diagonal	3	3-2-1(L) 4-5-6(R)	Diagonal up/outward, Vertical down	Shoulder abduction, extension, elbow flexion
			3-1-2(L) 4-6-5(R)	Diagonal down/outward, Vertical up	Shoulder abduction, flexion, elbow extension
			1-2-3(L) 6-5-4(R)	Vertical up, Diagonal down/inward)	Shoulder flexion, adduction, elbow extension/flexion
			2-1-3(L) 5-6-4(R)	Vertical down, Diagonal up/inward	Shoulder extension, adduction, elbow flexion/extension
		4	3-2-1-3(L) 4-5-6-4(R)	Diagonal up/down, Vertical down	Shoulder ab/adduction, extension, elbow extension/flexion
			3-1-2-3(L) 4-6-5-4(R)	Diagonal up/down, Vertical up	Shoulder ab/adduction, flexion, elbow extension/flexion
			3-2-1-2(L) 4-5-6-5(R) 3-1-2-1(L) 4-6-5-6(R)	Diagonal up/down, Vertical up/down	Shoulder ab/adduction, extension/flexion, elbow extension/flexion
	Diagonal+Diagonal	3	1-3-2(L) 6-4-5(R)	Diagonal up in/outward	Shoulder ab/adduction, flexion, elbow extension
			2-3-1(L) 5-4-6(R)	Diagonal down in/outward	Shoulder ab/adduction, extension, elbow extension/flexion
		4	3-2-3-1(L) 4-5-4-6(R) 3-1-3-2(L) 4-6-4-5(R)	Diagonal up/down, in/outward	Shoulder ab/adduction, flexion/extension, elbow extension/flexion

L: Left hand, R: Right hand

TIMP Intervention - Keyboard



Movement	Characteristic of Movement	Finger Use	Sequence	Keyboard Use	Hand/Finger Function
Single note playing	Isolated single finger movement	1	1, 2, 3, 4, 5	C, D, E, F, G	Finger range of motion, extension/flexion, strength, motor control
Repetition			1-1-1, 2-2-2…	C-C-C, D-D-D…	
Consecutive playing	Playing with two (or more) adjacent fingers	2	1-2	C-D	Finger range of motion, extension/flexion, strength, motor control
		3	1-2-3	C-D-E	
		4	1-2-3-4	C-D-E-F	
		5	1-2-3-4-5	C-D-E-F-G	
Interval playing	Playing with two (or more) fingers with interval(s) alternatively	2	1-3	C-E	Finger range of motion, extension/flexion, adduction, strength, motor control, wrist flexion/extension
		2	1-4	C-F	
		2	1-5	C-G	
		3	1-3-5	C-E-G	
		3	1-2-5	C-D-G	

Movement	Characteristic of Movement	Finger Use	Sequence	Keyboard Use	Hand/Finger Function
Chord playing	Playing with two (or more) fingers simultaneously	2	1-2	C-D	Finger range of motion, extension/flexion, abduction/adduction, strength, motor control, wrist flexion/extension
		2	1-3	C-E	
		2	1-4	C-F	
		2	1-5	C-G	
		3	1-3-5	C-E-G	
		3	1-2-5	C-D-G	
		5	1-2-3-4-5	C-D-E-F-G	
Patient-chosen song playing	Playing with two (or more) fingers randomly	1~5	1~5 (+more)	C, D, E, F, G (+more)	Finger range of motion, extension/flexion, abduction/adduction, strength, motor control, wrist flexion/extension
Patient-chosen song playing	Easy	1~5	1~5 (+more)	consecutive 3~5 notes	
	Medium			interval 3~5 notes	
	Advanced			consecutive and/or interval 5~8 notes	

*Any steps in the keyboard playing involving consecutive playing or interval playing can be followed by chord playing.

List of Songs for Keyboard Playing

* Easy (3-5 notes, consecutive playing)

Itsy Bitsy Spider

Marry Had a Little Lamb

Ode to Joy

* Medium (3-5 notes, interval playing)

Here We Go Round the Mulberry Bush

Old Macdonald Had a Farm

Oh When the Saints Go Marching In

Row Row Row Your Boat

Skip to My Lou

Twinkle Twinkle Little Star

* Advanced (5-8 notes, consecutive and interval playing)

Amazing Grace

Chopsticks

Happy Birthday to You

Oh Susanna

Silent Night

You are My Sunshine

Treatment Fidelity Checklist

Date: Name:

Please select "Yes" or "No" in response to the following questions.

1. Did the interventionist provide a music therapy intervention that included a warm-up period (i.e., simple stretching), gross motor skills (via drum playing), fine motor skills (via keyboard playing), and a cool-down period (i.e., simple deep breathing exercise)?

Yes_____ No_____

2. Did the interventionist provide various arm reaching exercises via drum playing?

Yes_____ No_____

3. Did the interventionist increase the complexity of drum playing by adding drum target(s) or increasing the distance between drum target(s) or mixing the sequence of drum target(s) after the participant completed the previous task?

Yes_____ No_____

4. Did the interventionist provide opportunities for practicing gross motor skills?

Yes_____ No_____

5. Did the interventionist provide various finger exercises via keyboard playing?

Yes_____ No_____

6. Did the interventionist increase the complexity of keyboard playing by adding keyboard target(s) or increasing the distance of keyboard target(s) or mixing the sequence of keyboard target(s) after the participant competed the previous task?

Yes_____ No_____

7. Did the interventionist provide opportunities for practicing fine motor skills via finger movements?

Yes_____ No_____

8. Did the interventionist provide musical prompts/cues (accompaniment via musical elements such as pitch, rhythm, dynamic, etc.) while the participant engaged in arm and hand exercises?

Yes_____ No_____

9. Did the interventionist refer to and utilize the participant's preferred songs for the exercises?

Yes_____ No_____

APPENDIX D

Outcome Measures

Fugl-Meyer Assessment

Date______________________ Subject Initial _____________

I. Reflex Activity			none	Can be elicited	
Flexors: biceps and finger flexors Extensors: triceps			0 0	2 2	
		Subtotal I (max 4)			
II. Volitional movement within synergies			**none**	**partial**	**full**
Flexor synergy:Hand from contralateral knee to ipsilateral ear	Shoulder	retraction	0	1	2
		elevation	0	1	2
		abduction(90°)	0	1	2
		external rotation	0	1	2
	Elbow	Elbow flexion	0	1	2
	Forearm	supination	0	1	2
Extensor synergy:Hand from ipsilateral ear to the contralateral knee	Shoulder	Adduction/int.rotation	0	1	2
	Elbow	extension	0	1	2
	Forearm	pronation	0	1	2
		Subtotal II (max 18)			
III. Volitional movement mixing synergies			**none**	**partial**	**full**
Hand to lumbar spine	cannot be performed, hand in front of ASIS		0		
	hand behind of ASIS (no compensation)			1	
	hand to lumbar spine (no compensation)				2
Shoulder flexion 0°- 90°	immediate abduction or elbow flexion		0		
elbow at 0°	abduction or elbow flexion during movement			1	
forearm in neutral	complete flexion 90°, maintains 0° in elbow				2
Pronation/supination	no pronation/supination		0		
elbow at 90°	limited pronation/supination			1	
shoulder at 0°	complete pronation/supination				2
		Subtotal III (max 6)			
IV. Volitional movement with little or no synergy			**none**	**partial**	**full**
Shoulder abduction 0°- 90°	immediate supination or elbow flexion		0		
elbow at 0°	supination or elbow flexion during movement			1	
forearm pronated	abduction 90°maintains extension pronation				2
Shoulder flexion 90° - 180°	immediate abduction or elbow flexion		0		
elbow at 0°	abduction or elbow flexion during movement			1	
forearm in neutral	complete flexion, maintains 0° in elbow				2
Pronation/supination	no pronation/supination		0		
elbow at 0°	limited pronation/supination			1	
shoulder at 30° - 90°	full pronation/supination, elbow extension				2
		Subtotal IV (max 6)			
V. Normal Reflex Activity *(evaluated only if full score of 6 points achieved on part IV)*					
biceps, triceps, finger flexors	0 points on part IV or 2 or 3 reflexes markedly hyperactive		0		
	1 reflex markedly hyperactive or at least 2 reflexes lively			1	
	maximum of 1 reflex lively, none hyperactive				2
		Subtotal V (max 2)			

Subtotal I – V (max36) ________

VI. Wrist stability/mobility (support may be provided at the elbow, no support at wrist)		**none**	**partial**	**full**
Stability at 15° extension shoulder at 0° elbow at 90°, forearm pronated	less than 15° wrist extension wrist extension 15°, no resistance taken maintains position against resistance	0	1	2
Repeated wrist flexion/extension shoulder at 0° elbow at 0°, forearm pronated	cannot perform limited active range of motion full active range of motion, smoothly	0	1	2
Stability at 15° extension shoulder at 30° - 90° elbow at 0°, forearm pronated	less than 15° wrist extension wrist extension 15°, no resistance taken maintains position against resistance	0	1	2
Repeated wrist flexion/extension shoulder at 30° - 90° elbow at 0°, forearm pronated	cannot perform limited active range of motion full active range of motion, smoothly	0	1	2
Circumduction	cannot perform jerky movement or incomplete complete and smooth circumduction	0	1	2
	Subtotal VI (max 10)			

VII. Hand (support may be provided at the elbow to keep 90° flexion, no support at the wrist)		**none**	**partial**	**full**
Mass flexion (from full active or passive extension)		0	1	2
Mass extension (from full active or passive extension)		0	1	2
Grasp				
A Hook: extend MCP, flex PIP/DIP digit II – V test against resistance	cannot be performed can hold position but weak maintains position against resistance	0	1	2
B Radial/Thumb: thumb adduction test with paper	cannot be performed can hold paper but not against tug can hold paper against tug	0	1	2
C Pincer: pulpa approximation of digit I and II test with pencil	cannot be performed can hold pencil but not against tug can hold pencil against tug	0	1	2
D. Cylindrical: opposition of digit I and II test with bottle	cannot be performed can hold bottle but not against tug can hold bottle against tug	0	1	2
E Spherical: fingers and thumb opposed test with ball	cannot be performed can hold ball but not against tug can hold ball against tug	0	1	2
	Subtotal VII (max 14)			

VIII. Coordination/Speed (nose to knee in rapid succession 5 times, eye closed)		**marked**	**slight**	**none**
Tremor		0	1	2
Dysmetria	pronounced or unsystematic slight and systematic no dysmetria	0	1	2
Time	more than 5 sec slower than less-affected side 2-5 seconds slow than less-affected side maximum difference of 1 second between sides	0	1	2
	Subtotal VIII (max 6)			

Subtotal VI – VIII (max 30) ____________

Total (max 66) __________

Wolf Motor Function Test

Date______________________ Subject Initial _________________

Task	Time	Functional Ability	Comments
1. Forearm to table (side)	___________	0 1 2 3 4 5	____________________
2. Forearm to box (side)	___________	0 1 2 3 4 5	____________________
3. Extend elbow (side)	___________	0 1 2 3 4 5	____________________
4. Extend elbow (weight)	___________	0 1 2 3 4 5	____________________
5. Hand to table (front)	___________	0 1 2 3 4 5	____________________
6. Hand to box (front)	___________	0 1 2 3 4 5	____________________
7. Weight to box _____lbs.	___________	0 1 2 3 4 5	____________________
8. Reach and retrieve	___________	0 1 2 3 4 5	____________________
9. Lift can	___________	0 1 2 3 4 5	____________________
10. Lift pencil	___________	0 1 2 3 4 5	____________________
11. Lift paper clip	___________	0 1 2 3 4 5	____________________
12. Stack checkers	___________	0 1 2 3 4 5	____________________
13. Flip cards	___________	0 1 2 3 4 5	____________________
14. Grip strength _____kbs.	___________	0 1 2 3 4 5	____________________
15. Turn key in lock	___________	0 1 2 3 4 5	____________________
16. Fold towel	___________	0 1 2 3 4 5	____________________
17. Lift basket	___________	0 1 2 3 4 5	____________________

Functional Ability Scale

Score	Description
0	Does not attempt with UE being tested
1	UE being tested does not participate functionally; however, an attempt in made to use the UE. In unilateral tasks, the UE not being tested may be used to move the UE being tested.
2	Does, but requires assistance of the UE not being tested for minor readjustments or change of position, or requires more than 2 attempts to complete, or accomplishes very slowly. In bilateral tasks, the UE being tested may serve only as a helper.
3	Does, but movement is influenced to some degree by synergy or is performed slowly or with effort.
4	Does; movement is close to normal *but slightly sower; may lack precision, fine coordination, or fluidity.
5	Does; movement appears to be normal*

*For the determination of normal, the less-involved UE can be utilized as an available index for comparison, with premorbid UE

Box and Block Test

Date______________________ Subject Initial ______________

Dominant Hand (Circle one): Right, Left

"I want to see how quickly you can pick up one block at a time with your right (or left) hand [point to the hand]. Carry it to the other sixe of the bow and drop it. Make sure your fingertips cross the partition." (Three cubes demonstration)
"If you pick up two blocks at a time, they will count as one, If you drop one on the floor or table after you have carried it across, it will still be counted, so do not waste your time picking it up. If you toss the blocks without your fingertips crossing the partition, they will not be counted." (Test trial)
"This will be the actual test. The instructions are the same. Try to work as quickly as you can." "Ready." [wait 3 seconds] "Go." "Stop."

Number of blocks transported (in one minute)

Date ______ Dominant Hand ______ Non-Dominant Hand ______

Date ______ Dominant Hand ______ Non-Dominant Hand ______

Date ______ Dominant Hand ______ Non-Dominant Hand ______

Date ______ Dominant Hand ______ Non-Dominant Hand ______

Stroke Impact Scale

Date______________________ Subject Initial _____________

Strength
The questions are about the physical problems which may have occurred as a result of your stroke.

In the past weeks, how would you rate the strength of your…

1.	Arm that was <u>most affected</u> by your stroke?	5 4 3 2 1
2.	Grip your hand that was <u>most affected</u> by your stroke?	5 4 3 2 1
3.	Leg that was <u>most affected</u> by your stroke?	5 4 3 2 1
4.	Foot/ankle that was <u>most affected</u> by your stroke?	5 4 3 2 1

ADL/IADL
The following questions are about activities you might do during a typical day.

In the past 2 weeks, how difficult was it to…

1.	Cut your food with a knife and folk?	5 4 3 2 1	
2.	Dress the top part of your body?	5 4 3 2 1	
3.	Bathe yourself?	5 4 3 2 1	
4.	Clip your toenails?	5 4 3 2 1	
5.	Get to the toilet on time?	5 4 3 2 1	
6.	Control your bladder (not have an accident)?	5 4 3 2 1	
7.	Control your bowels (not have an accident)?	5 4 3 2 1	
8.	Do light household tasks/chores (make a bed, take out garbage, do the dishes)?	5 4 3 2 1	(e.g., dust,
9.	Go shopping?	5 4 3 2 1	
10.	Do heavy household chores (e.g., vacuum, laundry, or hard work)?	5 4 3 2 1	

Hand function
The following questions are about your ability to use your hand that was most affected by your stroke.

In the past 2 weeks, how difficult was it to use your hand that was most affected by your stroke to…

1.	Carry heavy objects (e.g., bag of groceries)?	5 4 3 2 1
2.	Turn a doorknob?	5 4 3 2 1
3.	Open a can or jar?	5 4 3 2 1
4.	Tie a shoe lace?	5 4 3 2 1
5.	Pick up a dime?	5 4 3 2 1

Functional Score Scale

Score	Description (Strength)	Score	Description (Difficulty)
5	A lot of strength	5	Not difficult at all
4	Quite a bit of strength	4	A little difficult
3	Some strength	3	Somewhat difficult
2	A little strength	2	Very difficult
1	No strength at all	1	Could not do at all

Apraxia Screen of TULIA (AST)

Date______________________ Subject Initial __________________

Imitation

General instruction: **"Seven gestures are demonstrated in a mirror fashion, imitate them as precisely as possible"**

Task	Left
1. Bring thumb extended on forehead, other fingers point upwards	0 1
2. Wipe dust from shoulder	0 1

<u>Additional instruction</u>

"For the next five gesture, imagine holding a tool or an object in hand, don't use your fingers as a tool"

3. Drink from a glass	0 1
4. Smoke a cigarette	0 1
5. Use a hammer	0 1
6. Use scissors	0 1
7. Use a stamp to postmark	0 1

Pantomime

General instruction: **"Now gestures are asked. Listen very carefully and perform them as precisely as possible"**

8. "Show as if some is crazy"*	0 1
9. "Make a threatening sign"**	0 1

*repetitive tapping of the index finger at the temple (rotating movements of index finger are also correct

**upraise clenched fist (upraised index finger or open hand are also correct)

<u>Additional instruction</u>

"Again, imagine holding a tool or an object in hand, don't use the fingers"

10. "Brush your teeth"	0 1
11. "Comb your hair"	0 1
12. "Use a screwdriver"	0 1

Dichotomous Scale

Score	Description
0 **(Fail)**	-Appearance of body part as object errors -Considerable spatial errors, extra movements and omissions, false end position, substitutions and perseverations -Amorphous or seeking movements, not related to the desired gesture
1 **(Pass)**	-Normal movement -Slight slowdown or discrete spatial errors (e.g., diminished amplitude) are allowed -Discrete extra movements or omissions can occur -Also when brief substitutions or preservations occur, which are corrected, the score is still given

Pantomime-to-Photograph Matching Test

Date ______________________ Subject Initial _________________

Pantomime recognition:
Ask the patient to "Show me the one I am pretending to use"

Pantomime Auditory Recognition Acton + Targeted Tool	Score 1 or 0	Errors (Circle one) Semantic category	Function associate	Motoric
Glass to drink water out of	______	Tea cup	Water pitcher	Banana
Cigarette to smoke	______	Tobacco pipe	Match	Balloon
Hammer to pound a nail	______	Wrench	Nail	Potato masher
Scissors to cut paper	______	Shears	Paper	Pliers
Stamp to postmark	______	Licking stamp	Envelope	Hammer
Toothbrush to brush your teeth	______	Floss	Toothpaste	Lipstick
Comb to fix your hair	______	Brush	Hair	Hat
Screwdriver to turn a screw	______	Chisel	Screw	Key

APPENDIX E

Data for Upper Extremity Measures

Raw Data of Fugl-Meyer Test

Participant	Baseline	Pretest	Posttest	Follow-up	Pre-Post % change	Post-FW % change
	Total					
1	13	12	15	18	25	20
2	58	59	62	62	5.08	0
3	18	18	21	20	16.67	-4.76
4	31	31	41	44	32.26	7.32
5	17	16	22	21	37.5	-4.55
6	43	44	51	53	15.9	3.92
7	60	61	62	61	1.64	-1.61
	Proximal					
1	11	10	13	14	30	7.69
2	29	30	33	33	10	0
3	12	12	14	13	16.67	-7.14
4	21	22	26	29	18.18	11.54
5	12	11	14	13	27.27	-7.14
6	21	21	26	28	23.81	7.69
7	33	34	34	33	0	-2.94
	Distal					
1	2	2	2	4	0	100
2	29	29	29	29	0	0
3	6	6	7	7	16.67	0
4	10	9	15	15	66.67	0
5	5	5	8	8	60	0
6	22	23	25	25	8.7	0
7	27	27	28	28	3.7	0

Raw Data of Wolf Motor Function Test

Participant	Baseline	Pretest	Posttest	Follow-up	Pre-Post % change	Post-FW % change
	WMFT-TIME					
1	51.55	52.39	29.5	38.46	-43.69	30.37
2	3.27	3.36	2.19	2.37	-34.82	8.22
3	66.03	66.7	28.22	21.63	-57.69	-23.35
4	37.01	46.1	19.03	19.72	-58.72	3.63
5	52.01	49.68	33.87	37.74	-31.82	11.43
6	20.23	14.46	6.61	5.16	-54.29	-21.94
7	3.94	4.43	3.00	3.04	-32.21	1.23
	WMFT-FAS					
1	0.87	0.6	1.53	1.73	155	13.07
2	4.8	4.73	4.8	4.87	1.48	1.46
3	0.67	0.87	1.67	1.67	91.95	0
4	1.73	1.53	2.53	2.6	65.36	2.67
5	0.87	0.8	2	2	150	0
6	2.33	2.33	2.67	2.8	14.59	4.87
7	4.47	4.4	4.47	4.4	1.59	-1.57
	Strength					
1	10.6	5.6	9.80	2.7	75	-72.45
2	28.8	30.4	27.6	30.2	-9.21	9.42
3	0	2.4	2.2	3.1	-8.33	40.9
4	20.6	20.2	30.2	33.0	49.5	9.27
5	15.0	13.7	18.2	20.0	32.9	9.9
6	20.2	20.6	23.0	26.6	11.65	15.65
7	70.6	70.2	73.8	70.8	5.13	-4.07

Descriptive Analysis for Wolf Motor Function Test-Time

WMFT-TIME with the imputed values (e.g., 120 sec)

	Baseline	*Pre*	*Post*	*Follow-up*
Mean	33.43	33.87	17.49	18.30
Standard Deviation	22.99	23.89	12.49	14.43

WMFT-TIME without the imputed values (e.g., missing data)

	Baseline	*Pre*	*Post*	*Follow-up*
Mean	6.58	7.12	4.21	3.86
Standard Deviation	4.75	3.50	2.79	1.61

Raw Data of Box and Block Test

Participant	Baseline	Pretest	Posttest	Follow-up	Pre-Post % change	Post-FW % change
	BBT-R					
1	0	0	0	0	0	0
2	27	26	28	32	7.69	14.29
3	0	1	2	3	50	50
4	0	0	5	2		-60
5	0	0	0	0	0	0
6	11	10	15	17	50	13.33
7	25	25	26	30	4	15.38
	BBT-L					
1	52	60	63	63	5	0
2	31	35	34	34	-2.86	0
3	44	50	57	52	14	-8.77
4	28	33	37	44	12.12	18.92
5	55	57	64	67	12.28	4.69
6	24	29	29	25	0	-13.79
7	43	46	48	47	4.35	-2.08

Raw Data of Stroke Impact Scale

Participant	Baseline	Pretest	Posttest	Follow-up	Pre-Post % change	Post-FW % change
	Strength					
1	56.25	56.25	50	62.5	-11.11	25
2	62.5	62.5	81.25	87.5	30	7.69
3	25	18.75	43.75	37.5	133.33	-14.29
4	37.5	37.5	37.5	62.5	0	66.67
5	50	37.5	43.75	43.75	16.67	0
6	50	43.75	56.25	50	28.57	-11.11
7	100	100	100	100	0	0
	ADL					
1	42.50	47.5	65	72.5	36.84	11.54
2	70	72.5	80	87.5	10.34	9.38
3	57.5	60	60	65	0	8.33
4	70	70	67.5	80	-3.57	18.52
5	42.5	50	57.5	70	15	21.74
6	45	35	50	52.5	42.86	5
7	97.5	95	97.5	97.5	2.63	0
	Hand					
1	30.00	45	75	55	66.67	-26.67
2	80	85	90	85	5.88	-5.56
3	35	25	25	30	0	20
4	5	10	35	35	250	0
5	10	20	15	45	-25	200
6	25	35	55	45	57.14	-18.18
7	90	90	95	80	5.56	-15.79

Correlations between Outcome Measures

	FMA-Total	FMA-Proximal	FMA-Distal	WMFT-Time	WMFT-FAS	BBT-Right	SIS-Strength	SIS-ADL	SIS-Hand
FMA - Total	1.00								
FMA - Proximal	0.98	1.00							
FMA- Distal	0.98	0.93	1.00						
WMFT Time	-0.90	-0.87	-0.89	1.00					
WMFT FAS	0.94	0.92	0.92	-0.90	1.00				
BBT - Right	0.93	0.88	0.94	-0.84	0.95	1.00			
SIS - Strength	0.73	0.75	0.68	-0.70	0.80	0.80	1.00		
SIS - ADL	0.60	0.70	0.50	-0.53	0.72	0.61	0.73	1.00	
SIS - Hand	0.71	0.70	0.70	-0.71	0.83	0.83	0.82	0.69	1.00