Playing piano to enhance upper extremity function after stroke

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STATEMENT OF ORIGINALITY

I attest that this thesis contains no material previously published or written by someone else, except where due references are provided. The presented study represents original material and contributes to the advancement of knowledge in the field of post-stroke upper extremity as well as neuroscience and music.
ACKNOWLEDGMENTS

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I would like to dedicate this thesis to my parents to whom I owe my love for learning and music. Thank you for instilling in me the importance of hard work, patience and compassion for others and more importantly, thank you for believing in me. I am grateful for your endless love and support. To all my family and friends, thank you for your encouragement and understanding. Finally, my acknowledgement would be incomplete without thanking my husband and beloved partner. I could not carry on without you. You were there for me during these past few years, teasing me as always, but constantly encouraging me and pushing me forward.
CONTRIBUTION OF AUTHORS

This thesis is presented in manuscript format. The manuscript will be submitted for publication in *Neurorehabilitation and Neural Repair Journal*. I, Myriam Villeneuve, was the principal investigator of the manuscript entitled “Piano Training Improves Manual Dexterity and Upper Extremity Function in Chronic Stroke Survivors”, co-authored with Dr. Anouk Lamontagne and Dr. Virginia Penhune, who provided suggestions and critical review on the content as well as constructive comments on the structure of the manuscript. My personal contribution includes the literature review, design of the study and training intervention, recruitment of participants, training of participants, data collection and analysis, as well as the preparation of the manuscript for publication, under Dr Anouk Lamontagne’s supervision and guidance. As a member of my thesis committee, Dr. Eva Kehayia provided insightful suggestions on the study design and recruitment options.
This thesis consists of one manuscript that is being prepared for publication in a scientific journal. It follows the guidelines in conformity with the Faculty of Graduate and Postdoctoral Studies at McGill University.

This thesis is organized in 4 chapters. Chapter 1 is a review of the literature and covers the areas relevant to this thesis. Chapter 2 provides the rationale, objectives and hypotheses. Chapter 3 consists of a manuscript entitled, “Piano Training Improves Manual Dexterity and Upper Extremity Function in Chronic Stroke Survivors”. Chapter 4 summarizes the findings and presents the conclusion of the thesis.
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ABSTRACT

Persons with stroke often experience persistent contralateral sensorimotor impairments, which leads to activity and participation limitations. Previous research has shown that the use of piano training in rehabilitation can improve fine and gross motor skills in acute and chronic stroke survivors. It remains unknown, however, whether all stroke individuals respond similarly to an intervention involving structured and home practice and whether gains can be maintained over time. In addition, the creation of a piano training protocol with defined training parameters and criteria for progression is still lacking. The purpose of this study was to estimate the short-term and retention effects of a 3-week piano training program on upper extremity (UE) function in persons with chronic stroke. A multiple pre- multiple post-sequential design was used. Thirteen participants with chronic stroke (6 months to 9 years) engaged in a 3-week structured piano training (9 sessions of 60 minutes), in addition to home practice that consisted of piano exercises played on a flexible piano keyboard. As the participants progressed, the frequency (beat per minutes) and complexity (finger sequences) of the musical pieces increased. A MIDI-piano program (Synthesia) was used to display musical pieces involving all 5 digits of the paretic hand, and was designed to play piano without having to read musical scores. Clinical measures of upper extremity function were performed at baseline, pre-, post-intervention and at 3-week follow-up, using the Box and Block Test (gross manual dexterity), Nine Hole Peg Test (fine manual dexterity), Finger to Nose Test (upper extremity coordination), Finger Tapping Test (fine finger coordination) and Jebsen Hand Function Test (functional use of the upper extremity). Piano performance measures, including note accuracy and piece duration, were collected during the training sessions using Synthesia. Participants completed 2 to 9 pieces during the training period, progressing through consecutive finger sequences to sequences involving chords. A linear mixed model analysis for repeated measures revealed a significant effect of the intervention on all clinical measures of UE function (p<0.0001). Post-intervention scores were significantly larger compared to pre-intervention scores (p<0.0001), and no differences were observed between post-intervention and follow-up (p>0.5). The magnitude of changes in motor function induced by the intervention was not significantly associated to age and chronicity (Pearson correlation coefficients, r = 0.01 to 0.27, p≥0.3). Participants with better gross manual dexterity at baseline,
however, displayed larger improvements in gross manual dexterity and in the functional use of the upper extremity ($r = 0.64$ to $0.70$, $p < 0.01$). Altogether, findings indicated that a short piano-specific training can improve fine and gross manual dexterity, arm and finger movement coordination, as well as the functional use of the UE in persons with a chronic stroke. Results further suggest that participants with a higher level of motor recovery at baseline may benefit the most from this intervention, as they show larger improvements in manual dexterity and functional use of the upper extremity. The maintenance of the gains at the 3-week follow-up further suggests that the intervention has the potential to lead to long-lasting improvements. Such individually-tailored piano program has the potential to be continued beyond the usual rehabilitation period, leading to further improvements in UE function.
ABRÉGÉ

Les personnes ayant subi un accident cardio-vasculaire cérébral (AVC) éprouvent souvent des troubles sensorimoteurs contralatéraux persistants, entraînant des limitations au niveau des activités et de la participation. Il a été démontré que l’utilisation d’un entraînement au piano peut améliorer les habiletés motrices fines et grossières après un AVC aiguë et chronique. Cependant, il n’a pas encore été démontré si tous les individus répondent de manière similaire à une intervention comprenant à la fois une pratique structurée combinée à des pratiques à la maison, ni si les effets sont maintenus à long terme. De plus, aucun protocole d’entraînement de piano détaillé (paramètres d’entraînement et de progression) n’a été élaboré. L’objectif de cette étude était d’estimer les effets à court et moyen terme d’un programme d’entraînement au piano de 3 semaines sur la fonction du membre supérieur auprès de personnes ayant subi un AVC chronique. Un devis séquentiel de mesures multiples en pré- et post-intervention a été utilisé. Treize personnes ayant subi un AVC chronique (6 mois à 9 ans) ont participé à un entraînement de piano de 3 semaines (9 sessions de 60 minutes), complété par des pratiques à la maison. La fréquence (battements par minute) et la complexité (séquence de doigts) des pièces musicales augmentaient graduellement, suivant la progression des participants. Un programme MIDI d’apprentissage du piano (Synthesia) conçu pour jouer du piano sans avoir besoin de lire des partitions et a été utilisé pour présenter des pièces sollicitant les cinq doigts de la main parétique. La fonction du membre supérieur a été évaluée à quatre reprises à l’aide de tests cliniques administrés à trois semaines d’intervalle (initial, pré-, post-intervention et suivi), soit le Box and Block Test (dextérité grossière), le Nine Hole Peg Test (dextérité fine), le Finger to Nose Test (coordination du membre supérieur), le Finger Tapping Test (coordination fine des doigts) et le Jebsen Hand Function Test (utilisation fonctionnelle du membre supérieur). Les mesures de performance au piano (précision et durée d’exécution des pièces) ont été collectées lors de chaque session à l’aide de Synthesia. Les participants ont complété 2 à 9 des pièces musicales durant la période d’entraînement. Un modèle d’analyse linéaire mixte pour mesures répétées a démontré un effet significatif de l’intervention pour chacune des mesures cliniques utilisées (p<0.0001). Après l’intervention, les résultats étaient significativement plus élevés que les résultats collectés avant l’intervention (p<0.0001), et aucune différence n’a été observée entre
les résultat en post-intervention et au suivi (p>0.5). La magnitude des changements de fonction motrice n’était pas significativement associée à l’âge et à la chronicité (coefficients de corrélation Pearson, r = 0.01 à 0.27, p≥0.3). Les participants ayant une meilleure dextérité manuelle grossière initiale ont démontrés des améliorations plus élevées au niveau de la dextérité grossière ainsi que de l’utilisation fonctionnelle du membre supérieur (r = 0.64 à 0.70, p<0.01). Ces résultats indiquent qu’un court entraînement au piano peut améliorer la dextérité fine et grossière, la coordination du bras et des doigts ainsi que l’utilisation fonctionnelle du membre supérieur auprès de personnes ayant subi un AVC chronique. Les résultats suggèrent que les participants présentant un niveau de récupération moteur initial plus élevé pourraient bénéficier davantage de l’intervention, puisqu’ils démontrent de plus grands gains au niveau de la dextérité grossière et de l’utilisation fonctionnelle du membre supérieur. La stabilité des résultats après un suivi de 3 semaines suggère que l’intervention a le potentiel d’entraîner des gains persistants. Ce programme personnalisé a aussi le potentiel d’être poursuivi au-delà de la période usuelle de réadaptation et de mener à des améliorations additionnelles au niveau de la fonction du membre supérieur.
CHAPTER 1: REVIEW OF LITERATURE

One of the most severe acquired diseases associated with persistent motor impairments is stroke. It is defined as a sudden loss of brain function caused by the interruption of blood flow to the brain (ischemic stroke) or the rupture of blood vessels (hemorrhagic stroke), causing brain cells (neurons) in the affected area to die (Heart and Stroke Foundation of Canada 2013). Despite many medical advances in management and prevention, stroke remains one of the leading causes of chronic disabilities in North America (American Heart Association 2013). The number of stroke victims is increasing as the population ages; however, a larger number of people survive the acute phase due to medical progress (Fang & Alderman 2001). Consequently, the number of stroke survivors requiring hospital care and community services is also increasing. It is estimated that 315,000 Canadians are living with the effects of stroke and that $3.6 billion is spent every year for professional services, hospital costs and decreased productivity (Public Health Agency of Canada 2011).

1.1 CONSEQUENCES OF STROKE ON UPPER EXTREMITY FUNCTION

Stroke is a health condition associated with a wide variety of impairments, influenced by the location, type and severity of the brain lesion (Kwakkel et al 2003). Hemiparesis or hemiplegia are the most common consequences of stroke. They typically affect the side of the body opposite to the brain lesion, also referred to as ‘contralateral side’ or ‘paretic side’, and they are the impairments most frequently treated by rehabilitation therapists (Doyle et al 2010, Mahawish & Otaiku 2012, Ottenbacher 1980). It corresponds to an alteration in the control properties of the voluntary motor system (Mayer 1997) that can range from mild to complete paralysis (Mahawish & Otaiku 2012). Hemiparesis is characterized by muscle weakness, altered muscle tone and involuntary muscle co-activation of antagonist muscles (Dovat et al 2010). Movement dysfunction arises from a complex interplay among muscle weakness, hypertonicity (spasticity) and other physical alterations in muscle and tissues, such as stiffness and contracture (Marciniak 2011, Mayer 1997). Muscle weakness results in the reduced efficiency or inability to generate and sustain sufficient force to produce a voluntary movement (Mayer & Eskenazi
2003). It can affect the upper and lower extremity as well as axial muscles controlling the neck and trunk (Bohannon 2007). Weakness is also present on the ‘non-paretic’ side (ipsilateral to the brain lesion) where muscle strength has been shown to range from 60% to 90% of normal values (Andrews & Bohannon 2000). In the upper extremity, muscles that are the most affected in terms of motor function include shoulder abductors, elbow flexors, wrist extensors and both finger flexors and extensors (Cho et al 2012). In general, however, proximal muscle strength (around shoulder and elbow joints) is less affected than that of distal muscles (wrist and finger muscles) (Andrews & Bohannon 2000, Cho et al 2012). This difference can be explained by distinct neural innervations: distal muscles are controlled by the lateral corticospinal tract, while proximal muscles are also innervated through extrapyramidal motor pathways (Cho et al 2012, Jang 2009).

It has also been shown that weakness of finger extensors is more severe than toe extensors in individuals with corticospinal tract injury following a stroke, suggesting that there is a greater involvement of the lateral corticospinal tract in motor function of the upper extremities as compared to lower extremities (Cho, et al. 2012).

Spasticity can be described as an excessive muscle tone characterized by a hyperactive and velocity-dependent response to muscle stretch (Burke et al 2013). Clinically, it results in an increased muscle tone and hyperactive tendon jerk reflex in individuals during active and passive movements (Burke et al 2013). Spasticity is commonly observed within the first few weeks to 3 months after stroke and may persist in the chronic stage (Marciniak 2011, Wissel et al 2013). Another manifestation of abnormal muscle recruitment is known as muscle co-contraction which is caused by involuntary activation of antagonist muscles while voluntarily activating agonist muscles (Mayer & Esquenazi 2003). Effort to voluntarily activate a muscle can also be dominated by abnormal muscle synergies (obligatory patterns of movement) which therefore cause movement dysfunction (Mayer 1997). For example, it is common for persons with stroke to adopt a clenched fist position. When they attempt to extend their fingers, finger flexor muscles (flexor digitorium sublimis and/or flexor digitorium profundus) are simultaneously activated (Mayer & Esquenazi 2003). As a result, persons with stroke show a reduced net muscle force (weakness) when executing a finger extension, which is caused not only by the paresis of the prime movers (finger extensors), but also by the abnormal co-contraction of antagonistic muscles (finger flexors). Clenched fist is a typical clinical presentation of synergy patterns in the upper
extremity, which also includes adducted and internally rotated shoulder, flexed elbow, pronated forearm, flexed wrist and thumb-in-palm deformity (Mayer & Esquenazi 2003).

Impairment in somatic sensation is also common after stroke and affects predominantly the contralateral side (Doyle et al 2010). Sensory deficits can include loss of detection of light touch sensation, vibration, pressure, as well as impairment in pinprick sensation, two-point discrimination, temperature detection, pain sensation, proprioception (orientation and position sense of body parts), depth sense and stereognosis (recognition of objects by touch) (Doyle et al 2010). The problems resulting from sensory impairments go beyond the loss of sensory information, as they can lead to secondary complications such as sores, abrasion and shoulder subluxation (Doyle et al 2010). It has also been shown that the amount of use of upper extremity and hand dysfunction (deficits in timing, coordination and efficiency of movement) are strongly and inversely correlated with the severity of sensory deficits (Nowak et al 2007, van der Lee et al 1999). Reduced coordination is one of the impairments that can affect the functional use of the upper extremity, which is a deficit in the control of strength, range, speed, direction and timing of body movements (Trombly & Radomski 2002). Impaired coordination has an impact on tasks requiring arm reaching and finger dissociation, and is therefore correlated with decreased upper extremity function (Dovat et al 2010, Levin 1996, McCrea et al 2002). Other impairments that can be observed after stroke and that may influence motor performance include visual field defects (e.g. hemianopsia), visuo-perceptual deficits such as visuospatial neglect, cognitive deficits, apraxia and aphasia (Trombly & Radomski 2002).

Because of sensorimotor impairments and reduced upper extremity function, persons with stroke experience difficulties with activities of daily living. It is estimated that 85% of persons with stroke experience upper extremity impairments as well as activity and participation limitations immediately after stroke (Hendricks et al 2002), and that these problems persist beyond 3 to 6 months in more than 50% of cases (Mayo et al 2002). Activity limitations that are commonly observed are related to basic activities of daily living (e.g. bathing, dressing, grooming, feeding), household tasks, mobility, as well as other meaningful activities such as leisure and vocational activities (Mayo et al 2002). These limitations were associated with decreased quality of life and reduced participation in the community (Mayo et al 2002).
One of the many challenges in stroke management is to offer long-term services and support to patients in order to increase their functional independence, prevent deterioration, and promote home and community reintegration, while taking into consideration the costly nature of hospital stay and rehabilitation services. In Canada, 58% of patients are discharged home directly from acute care while only 19% are transferred to in-patient rehabilitation facilities. In the latter group, 71% will return home after the rehabilitation phase and half of them will require on-going in-home services (Canadian Stroke Network 2011). Isolation and seclusion from community are common after hospital discharge, mostly due to physical and environmental barriers (Mayo et al 2002). As a result, more than 70% of community-dwelling stroke survivors report lacking meaningful activities, making them consequently more at risk for depression, or worsening health and quality of life (Carod-Artal et al 2000, Mayo et al 2002).

1.1.1 Upper Extremity Rehabilitation

The recovery of upper extremity function is crucial for performance of activities of daily living and individuals with stroke rate the return of arm function as a high priority goal in rehabilitation (Bohannon et al 1988). Recent evidence demonstrates that conventional therapy, including the Brunnstrom, Bobath/Neurodevelopmental and task-oriented approaches, only produces modest to moderate improvements in functional use of the upper extremity (Van Peppen et al 2004), possibly due to insufficient training intensity (Cooke et al 2010) and lack of adherence. Although the recovery of upper extremity function has been shown to be similar to that of the lower extremity, arm, hand and finger movement impairments may remain more problematic and have a greater impact on daily activities and participation (Duncan et al 1994, Rand & Eng 2012). This might be explained by the higher complexity and precision required to perform tasks that involve the upper extremity, including the hand and fingers, as compared to tasks performed with the lower limbs. Therefore, improvements observed after interventions targeting the upper extremity may not transfer as easily into increased performance in activity of daily living (Higgins et al 2006). Moreover, since stroke survivors are encouraged to recover their functional independence as early as possible, they tend to favor the use of the non-paretic arm, which can lead to a pattern of learned disuse of the paretic arm and further exacerbate the level of disability (Levin et al 2009, Rand & Eng 2012, Taub et al 2006). Further, they may use non-optimal compensation strategies with the paretic arm, such as increased trunk movement or
assistance for in-hand positioning during grasping, thus preventing true recovery from occurring (Cirstea & Levin 2007). While it has been shown that most of the recovery in upper extremity function naturally occurs within the first 3 to 6 months after a stroke, evidence suggests that rehabilitation has the potential to induce neurological and functional changes well beyond this early recovery window (Duncan et al 1994, Ferrarello et al 2011, Mayo et al 1999, Rossini & Dal Forno 2004). In fact, more that 6 months after stroke, slow relearning is still possible through brain reorganization and can extend throughout many years after stroke (Ferrarello et al 2011).

1.1.2 Existing Approaches in Upper Extremity Rehabilitation

Decades of research in stroke rehabilitation have lead to the elaboration of best practices that include interventions and strategies supported by scientific evidence. A number of upper extremity interventions are considered effective to improve function after stroke, including constraint-induced movement therapy (CIMT) and functional electrical stimulation (FES) (Canadian Stroke Network 2011). CIMT is one of the most studied rehabilitation techniques in the last decade. It consists of (1) the forced use of the paretic upper extremity by restraining movement of the less-affected side during many hours per day, coupled with (2) shaping and task exercises with the paretic upper extremity (Wolf et al 2006). CIMT was shown to significantly improve motor function in terms of quality and speed of movement of the paretic arm as well as the quality and amount of use of the arm in daily activities in a sub-acute stroke population (Page et al 2002, Wolf et al 2006). FES, a technique that uses small electrical pulses to activate the paretic muscles, has also been demonstrated to enhance upper extremity motor function and dexterity, notably wrist and finger extension in individuals with a sub-acute stroke (Hara 2008, Kimberley et al 2004, Wang et al 2002). Both CIMT and FES have been shown to be more effective than traditional therapy to improve hand function and manual dexterity, even when applied in the chronic phase of stroke (de Kroon et al 2002, Miltner et al 1999, Ottenbacher 1980, Oujamaa et al 2009, Peurala et al 2002). Preliminary evidence also supports the use of virtual reality as well as sensorimotor training with robotic devices to improve motor outcomes (Balasubramanian et al 2010, Henderson et al 2007, Lum et al 2002, Masiero et al 2007, Subramanian et al 2013). Motor imagery and mirror therapy are two other promising interventions for chronic stroke rehabilitation, as adjuncts to conventional therapy (Page et al 2007, Wu et al 2013).
1.1.3 Limitations to Existing Approaches

While the above-mentioned therapies can enhance upper extremity motor recovery and function, they also present some limitations. Interventions such as virtual reality, robot-assisted therapy and FES require the use of sophisticated and sometime costly equipment. The majority of these interventions also require a professional therapist to be present during the entire duration of the therapy to provide assistance and for security (risks associated with impaired cognition, impaired balance and impulsive behaviors). This is especially problematic for chronic stroke survivors who are discharged from the rehabilitation facility and who do not have access to this type of equipment. Moreover, therapies such as CIMT are very demanding and time-consuming. In fact, CIMT requires that the non-paretic arm be restrained for 90% of waking hours while intensively training the paretic arm 6 hours a day for a period of 2 to 3 weeks (Wolf et al 2006). Modified versions of this therapy (mCIMT) involve shorter training durations, but still necessitate at least 5 hours of non-paretic arm restraint and 3 to 5 hours per week of intensive training with the paretic arm (Sirtori et al 2009). As a consequence, persons with stroke might find it challenging or even unmanageable to pursue such therapy in the long-term.

It has been shown that improvements in hand function and manual dexterity can be observed long after the initial period of natural recovery after stroke (Oujamaa et al 2009, Page et al 2004). It is also reasonable to assume that a therapy that can be continued beyond the typical rehabilitation period may lead to larger and more sustainable improvements in upper extremity motor function and activity of daily living (Ferrarello et al 2011). Music-supported therapy, which relies on repetitive massive practice of finger movements and auditory-motor coupling (Schneider et al 2007), has recently been developed as a novel rehabilitation approach for the paretic upper extremity in stroke survivors. Because of its high motivational value (Altenmuller et al 2009), music-supported therapy has the potential to be continued in the long-term and to be self-managed by the participants. In the next sections, I will introduce the concept of music-supported therapy and present the principles underlying the training, followed by a review of the literature on existing musical training interventions in stroke rehabilitation. In Chapter 2, I will present my rationale for using piano as a training tool in stroke rehabilitation as well as the objectives and expected contributions of this research.
1.2 WHAT IS MUSIC THERAPY

1.2.1 Definition and Meaning of Music

One of the very pleasurable activities that is common to almost all human beings regardless of age and among every culture is music. Music differs from noise because of its “uniquely ordered structure of sensory patterns in aesthetic forms” (Thaut 2005). Brandt and colleagues provided a very inclusive definition of music: “Music is creative play with sound […]. The term “music” also implies a value placed on the acoustic parameters of envelope, frequency, and spectrum irrespective of any referential function […]. It can apply to any activity involved with the production and human perception of sound” (Brandt et al. 2012). Most individuals have been extensively exposed to music since birth and have developed preferences towards particular styles and instruments over their lifetime. Listening to music is meaningful because of its ability to move us emotionally (Chanda & Levitin 2013). Music also has the ability to move us physically and most people have the intrinsic ability to coordinate body movements to a musical rhythm (Chen et al. 2008). Since the dawn of time, humans have danced to music and marched to music, without formal musical training. Another physical manifestation of this natural power of music is that people often spontaneously snap their fingers or tap their feet to the beat of a song (Chen et al. 2008). The ability to move in time with music reflects an internal representation of the beat (Thaut et al. 2002); involving complex auditory-motor synchronization processes (Munte et al. 2002). Playing a musical instrument is another way humans move their bodies to create music. For many people, this is an enjoyable activity and the pleasant feeling comes likely from the ability to create aesthetic sounds from controlled and coordinated movements.

1.2.2 Origin of Music Therapy

Music has long been used to heal the body and soul. In Greek mythology, Apollo is the god of healing, a protector from evil and the god of music. Biblical texts dating from 1000 BC tell the story of David playing the harp to king Saul to liberate his soul from bad spirits. Many ancient physicians and philosophers such as Plato, Aristotle and Hippocrates associated music with the purification of the mind and recognized its powerful influence on emotions (Biley 1999). Native Americans also employed chants and dances to cure various diseases. Throughout the years, music has continued to be considered as a remedy in many civilizations and has been
associated with mental, emotional and spiritual wellbeing. Music therapy as we know it today began after the World Wars, when music was played in hospitals for soldiers suffering from physical and emotional trauma (Degmečić 2005). Since the mid-eighties, music therapy has become an emerging topic of interest for researchers, particularly in the field of mental disorders and physical medicine. According to the Canadian Association for Music Therapy, it is defined as “the skillful use of music and musical elements by an accredited music therapist to promote, maintain, and restore mental, physical, emotional, and spiritual health” (2013). In the context of this thesis, I will not review the use of music as a mean to promote emotional and psychosocial health. Instead, I will focus on its application in physical rehabilitation, with a special emphasis on stroke rehabilitation.

1.3 PRINCIPLES BEHIND THE USE OF MUSIC THERAPY IN PHYSICAL REHABILITATION

1.3.1 Musical Training Enhances Motor Performance and Induce Brain Plasticity

Our understanding of the effects of music on motor control and brain plasticity largely arises from research performed in musicians. Musicians, who are recognized for their highly specialized motor skills developed over a lifetime of extensive hours of training, differ from non-musicians in many ways. Amongst other things, they display highly sophisticated auditory (sound and music processing, pitch discrimination, rhythm representation and chord perception) and motor skills (finger dexterity and coordination) (Dawson 2011). The literature suggests that these differences are influenced by factors such as the age of training onset (younger age increases performance) as well as the intensity of practice (higher intensity associated with increased performance) (Dawson 2011, Watson 2006).

Compared to amateurs, professional musicians show greater finger independence and better control when regulating peak force and press duration of finger movements (Inui & Ichihara 2001, Parlitz et al 1998). Musicians also display more accurate synchronization abilities and timing accuracy while performing simple and novel motor sequences, compared to non-musicians (Kincaid et al 2002). They further exhibit better bimanual coordination (Verheul &
Geuze 2004) and less muscle co-contraction while playing their musical instrument (Fujii et al 2009).

While using imaging and electrophysiological techniques, many studies have also identified structural and functional brain differences between musicians and non-musicians. Compared to non-musicians, pianists were found to display an increased gray matter volume in the primary sensorimotor cortex, pre-motor cortex and cerebellum, regions that are related to motor learning and skill acquisition, or to the translation of musical notation into motor command (Gaser & Schlaug 2003, Han et al 2009). Evidence for increased activation in musicians as compared to non-musicians was observed in the pre-frontal cortex (Chen et al 2008), whereas reduced recruitment of cortical motor regions was shown in the primary motor cortex, premotor cortex, supplementary motor area (SMA), pre-SMA, and cerebellum (Jancke et al 2000, Koenke et al 2004, Krings et al 2000, Meister et al 2005). In the latter studies, it was suggested that musicians’ long-term training may result in greater efficiency of neural pathways, therefore requiring fewer neurons to be recruited. Functional differences can also be observed among musicians depending on the instrument played, reflecting cortical adaptations to the specific instrument requirements. For example, string players display an increased cortical representation of the left hand (Bangert & Schlaug 2006, Elbert et al 1995), which is associated with the larger demand for fine movements of the left hand (Stewart 2008). Taken together, these observations indicate that musical training can induce cortical changes along with enhanced motor performance.

1.3.2 Musical Training Induces Auditory-Motor Coupling

Performing music requires specialized cortical mechanisms that allow for rapid integration of complex motor commands with auditory feedback (Pantev & Herholz 2011, Zatorre et al 2007). During music performance, the sound of the instrument processed by the auditory cortex acts as feedback that is used by the motor cortex to adjust movements or correct errors in terms of timing, force and accuracy (Grau-Sanchez et al 2013). This feed-forward interaction between the auditory and motor systems in music processing is known as auditory-motor coupling (Zatorre et al 2007). The presence of auditory-motor coupling has been demonstrated in professional musicians. For example, when pianists passively listen to well-learned pieces, the contralateral motor cortex is active (Haueisen & Knosche 2001). Similarly,
when violinists are asked to silently tap a musical piece, activation of their auditory cortex can be detected (Lotze et al 2003). Musical training has been shown to contribute to the development of this auditory-motor coupling during the learning and training phases of music performance (Bangert et al 2006), which occurs within minutes after the beginning of practice in novice piano players (Bangert & Altenmuller 2003). Music might therefore provide an alternative stimulus to access and stimulate the motor cortex and foster brain plasticity by promoting strengthening of existing pathways or the formation of new ones.

1.3.3 Musical training involves key principles of motor learning and rehabilitation

Motor learning, or the acquisition of new motor skills, is optimized when there is task-specific practice performed in the context of a meaningful and motivating paradigm with sufficient repetition and training intensity. Sensory feedback is also an important element that favors the acquisition of new skills, as it provides instantaneous knowledge of results and/or performance (Bayona et al 2005, Butefisch et al 1995, Carey et al 2005, Cirstea & Levin 2007, Cooke et al 2010, Han et al 2013, Hubbard et al 2009, Parker et al 2011). Piano training requires intensive and repetitive training over time as well as task-specific practice, with an emphasis on the coordination of finger movements. It also relies on concurrent and explicit multisensory feedback. Auditory feedback acts as a major reinforcing cue as it immediately provides information about the movement outcome. Melody provides a constant feedback about movement accuracy, as finger movement sequences are instantly associated to the relevant musical outcome. Moreover, rhythm provides the temporal structure of music and gives feedback about the timing of movements. Additionally, tactile feedback is provided at finger-key contact, which has been suggested to enhance timing accuracy of finger movements during piano performance in pianists (Goebl & Palmer 2008). Finally, playing piano is an enjoyable and socially valued leisure activity associated with high motivation. Thus, because piano training involves key principles of motor learning and because it facilitates the activation of cortical motor areas through auditory-motor coupling (Bangert & Altenmuller 2003), it can represent an ideal intervention strategy for upper extremity function in persons with stroke.
1.4 MUSIC THERAPY IN STROKE REHABILITATION

1.4.1 Use of music and auditory information in physical rehabilitation

The literature reports a few rehabilitation techniques that use auditory information to promote locomotor and upper extremity recovery after a stroke. Studies using metronomes and/or music during gait training in stroke patients or survivors have demonstrated a significant improvement in gait parameters, including stride length, velocity, cadence and gait symmetry (Bangert & Altenmuller 2003, Bradt et al 2010, Hayden et al 2009, Hesse & Werner 2003, Hollands et al 2012, Kim et al 2011, Mauritz 2002, Schauer & Mauritz 2003, Thaut et al 2007, Wittwer et al 2013). Rhythmic auditory stimulation has also been shown to have a positive effect on gait velocity, cadence and stride length in other neurological conditions such as Parkinson’s disease (McIntosh et al 1997, Thaut et al 1996) and multiple sclerosis (Conklyn et al 2010). Rhythmic auditory stimulation has been shown to be useful to assist with the execution of arm movements during complex activities such as music and sports in healthy individuals (Thaut et al 2002). In persons with stroke, the presence of an auditory rhythm, compared to no temporal cues, resulted in significant and immediate improvement in kinematic stability while reaching with the paretic arm (Thaut et al 2002).

Auditory cues used in studies reported in the literature generally take two forms: 1) metronomes or rhythmic beat or 2) music. In a study investigating both types of cues in healthy elderly participants, it was shown that compared to a metronome, listening to music had a greater impact on spatiotemporal measures of gait, including velocity and stride length (Wittwer et al 2013). Therefore, both types of cues should not be considered as equivalent. Furthermore, auditory information can be used either as an external cue, entraining and stimulating movements, or as feedback on performance, reflecting the characteristics of the movement. Most rehabilitation paradigms, including those in the studies cited above, used auditory cues as an external pacemaker. Music-supported therapy, however, differs in that the auditory information is generated by the finger movements of the participant and provides feedback on the spatial (accuracy) and temporal (timing) features of these movements.
1.4.2 Evidence Supporting the Use of Music-Supported Therapy

Music-supported therapy is a therapeutic approach first introduced by Schneider and collaborators (Schneider et al 2007). In its original form, individuals were trained by an instructor to reproduce different musical sequences (tones, scales and simple melodies) on a MIDI-piano and electronic drum pads to improve fine and gross dexterity, respectively. One important assumption behind the use of music-supported therapy is that playing music stimulates complex sensorimotor processes in the brain, which might be generalized and transferred to nonmusical tasks and activities (Pantev & Herholz 2011, Thaut 2005, Zatorre et al 2007).

The use of music-supported therapy was first investigated in a randomized control trial involving acute (mean time after stroke: 1.9 months) stroke survivors (Altenmuller et al 2009, Schneider 2010, Schneider et al 2007). In this paradigm, the experimental group received both music-supported therapy and conventional physical therapy and was compared to a control group receiving only conventional therapy. The music training involved 15 sessions of 30 minutes each over 3 consecutive weeks. Motor function was assessed through a motor test battery (Action Research Arm Test [ARAT], Arm Paresis Test, Box and Block Test [BBT], and Nine Hole Peg Test [NHPT]) and a computerized movement analysis system (hand tapping, index-finger tapping, and pronation-supination). Significant improvements were observed for all parameters in the experimental group, with the exception of the pronation-supination coordination test. The effect sizes for participants in the music group were moderate for all parameters (between 0.4 and 0.6), with the exception of the pronation-supination test and the NHPT, which were reported to be small. For the control group, all effect sizes were qualified as being extremely small. Based on these findings, the authors suggested that music-supported therapy yielded larger improvement in terms of fine and gross motor skills with respect to speed, precision and smoothness of movement, as compared to conventional rehabilitation. Electroencephalographic (EEG) signals were also recorded pre- and post-intervention and results showed a larger post-intervention increase in beta-band coherence in the experimental group compared to the control group (Altenmuller et al 2009). These results were interpreted as evidence for neural reorganization, which was induced specifically by the musical training. In addition, the same research group conducted a parallel study based on the same data, but adding a third group receiving CIMT (Schneider 2010). Findings revealed that music-supported therapy led to greater improvements of motor function as compared to CIMT of equal training intensity. Recently, the same researchers conducted a study
on a small group of 9 sub-acute stroke participants (< 6 months after stroke) (Grau-Sanchez et al 2013) who received music-supported therapy delivered over a 4 week period (20 sessions of 30 minutes). Significant improvements on the ARAT, Arm Paresis Test and BBT scores were found when comparing post-intervention vs. pre-intervention scores, but no significant differences were observed on the NHPT. Interestingly, participants also scored higher on a scale assessing quality of life after the intervention. Transcranial magnetic stimulation (TMS) performed on 6 of the 9 participants also revealed that motor improvements were accompanied by changes in the excitability of the motor cortex, including a decrease in the active motor threshold and a displacement of the motor map.

Finally, this group recently tested the effectiveness of music-supported therapy in persons with chronic stroke (> 6 months after stroke), using the same training procedure described above (20 sessions of 30 minutes over 4 weeks). Results showed that the music group display larger improvements on the ARAT and the quality of rapidly alternating movements (assessed with computerized movement analysis of the whole hand tapping, index finger tapping and forearm pronation-supination) as a result of the intervention compared to the control group consisting of a matched sample of healthy individuals receiving no intervention (Amengual et al 2013, Rodriguez-Fornells et al 2012, Rojo et al 2011). In the experimental group receiving music-supported therapy, TMS further revealed an increase in motor cortex excitability of the affected hemisphere that was accompanied by an expansion of the cortical representation of the paretic hand muscles after the intervention. These changes, which were not present in the control group, were interpreted as evidence for reorganization of the motor cortex due to the musical training.

To date, existing studies on music-supported therapy arise from the same research group and employed a similar training paradigm. These studies, including two randomized controlled trials, support the use and effectiveness of music-supported therapy to improve motor outcomes and to induce cortical reorganization in persons with acute, sub-acute or chronic stroke. There also exist other promising therapeutic approaches that involve a component of musical training, such as virtual piano simulation with a MIDI-Glove (Friedman et al 2011) or a ‘CyberGlove’ (Merians et al 2011). In a group of 12 persons with a chronic stroke performing 4 different virtual reality games, including the virtual piano simulation, improvements in finger movement dissociation was observed after 8 training sessions (Merians et al 2011).

Although existing studies support the feasibility of music-supported therapy in acute and
chronic stroke survivors, some questions and limitations remain to be addressed. First, it is unknown whether the gains observed after music-supported therapy are maintained after the cessation of the training or whether they lead to longer-term improvements in motor function. Secondly, existing music-supported therapy programs involve 5-days/week training regimens that may be difficult to implement in outpatient and community rehabilitation settings. Furthermore, no previous training program has focused on finger movement accuracy, timing and speed, which are important determinant of finger coordination. It also remains unclear whether some individuals respond better to the intervention and what characteristics influence treatment response, such as age, initial motor function and time since stroke. Finally, the term “music-supported therapy” covers a wide range of studies not limited to those described above. However, only a few studies emphasize on a clear methodology including a descriptive and replicable protocol and measurable outcomes. Musical interventions should include the involvement of a trained therapist who has some degree of musical training and should use techniques based on scientific evidence, with the objective of inducing sustainable functional recovery (Raglio 2013). Therefore, there is a need to develop structured musical interventions that are replicable in clinical and home settings and that incorporate evidence-based principles in motor recovery.
CHAPTER 2: RATIONALE, OBJECTIVE AND HYPOTHESIS

2.1 RATIONALE

The rehabilitation literature indicates that interventions for upper extremity recovery after stroke should be meaningful and task-specific, tailored to the person’s capacity and interests while providing sufficient repetition and challenge to induce training effects. Ideally, intervention should further take advantage of sensory feedback, which gives instantaneous knowledge of result and/or performance. Music-supported therapy involves all of these principles of motor learning, while representing an enjoyable activity for most individuals. In addition, emerging evidence suggests that the rapid establishment of auditory-motor coupling underlies the efficacy of the music-supported therapy. This auditory-motor coupling can be initiated within minutes after onset of training in novice players (Bangert & Altenmuller 2003), which suggests (1) that no previous musical experience is needed to benefit from musical training and (2) that individuals with stroke can take advantage of the auditory feedback produced while playing to facilitate the activation of the motor cortex, which will in turn facilitate the production of movement. In other words, it is expected that auditory-motor coupling operates as a form of cortical facilitation that can have a powerful effect on brain plasticity.

Although music-supported therapy has been described as a promising intervention in stroke rehabilitation, several aspects still remain unknown.

1) Do all individuals with stroke respond similarly to the intervention? If individuals do not respond equally, the characteristics of people who respond best need to be identified.

2) Existing studies on music-supported therapy have included a mixed-instrument training that combines piano and drum pad practice. It is unknown whether piano-only training would lead to similar outcomes.

3) Existing studies on music-supported therapy lack a clear description of the piano training program in terms of training parameters and criteria for progression, which raises the question as to how or whether it was standardized across participants.
4) It is unknown whether music supported therapy leads to longer-term improvements in motor function after cessation of practice.

To make music-supported therapy more effective, feasible and available to a broader range of people, we thought it was important to test a combined training program that would include both supervised work with a therapist and home practice. We have developed an individually tailored piano training paradigm that targets finger movement coordination using a user-friendly computerized piano program. The training provides online feedback on note accuracy, timing and speed while allowing participants to progress through finger sequences of increasing complexity. The participants received 9 training sessions with a therapist and were provided with a portable keyboard for home practice. The training program was designed to rely on key principle of motor learning supported by evidence from the literature.

2.2 OBJECTIVES AND HYPOTHESES

The purpose of this study was to investigate the feasibility of an individually-tailored piano training intervention that combines structured piano lessons to home practice in chronic stroke survivors. The primary objective was to estimate the short-term and retention effects of a 3-week piano-specific training program on manual dexterity, finger movement coordination and functional use of upper extremity in persons with chronic stroke. The secondary objectives were to (1) examine the effect of the piano training program on piano performance and (2) to provide a detailed description of a piano training protocol that can be tailored to the needs and progression of the participants. The following hypotheses were examined:

1) Music supported therapy improves gross and fine manual dexterity, finger movement coordination as well as the functional use of upper extremity.
2) Music supported therapy improves performance on piano outcomes.
3) Participants may respond differently to the intervention depending on their clinical profile, including their age, chronicity and initial level of motor recovery.
4) Improvements, when present, will be maintained at the 3-week follow-up.
2.3 EXPECTED CONTRIBUTION AND SIGNIFICANCE

To our knowledge, this is the first study to investigate the feasibility of a structured piano-specific training program combining therapist-supervised and home practice. If the results are positive, they will support the use of music-supported therapy as a resource-effective adjunct therapy for the rehabilitation of upper extremity function in chronic stroke. It is anticipated that combining supervised therapy with a home program will further increase the efficacy of the treatment, the empowerment of the patient and lead to sustainable improvement in upper extremity function. Very importantly, providing a detailed operational description of the training protocol will potentially allow it to be implemented in outpatient or community settings, where a 5-days/week intervention might not be realistic. Because the program was designed to be self-managed, it will also enable individuals with stroke to pursue the training on the long term, outside the rehabilitation setting.
CHAPTER 3: MANUSCRIPT
A PIANO TRAINING PROGRAM TO IMPROVE MANUAL DEXTERITY AND UPPER
EXTREMITY FUNCTION IN CHRONIC STROKE SURVIVORS

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Music-supported therapy has been shown to induce improvements in motor skills in acute and chronic stroke survivors. It remains unknown, however, whether all stroke individuals respond similarly to the intervention and whether gains can be maintained over time. The creation of a piano-specific training protocol with clear parameters for progression is also lacking. The purpose of this study was to estimate the immediate and retention effects of a piano training program on upper extremity (UE) function in persons with chronic stroke. Thirteen stroke participants engaged in a 3-week piano training comprising of supervised sessions (9 x 60min) and home practice. Measures of fine and gross manual dexterity (Box and Block & Nine Hole Peg Tests), movement coordination (Finger Tapping & Finger to Nose Tests) and functional use of the UE (Jebsen Hand Function Test) were assessed at baseline, pre-, post-intervention and at follow-up. Significant improvements were observed on all clinical tests, with post-intervention scores that were larger compared to pre-intervention scores and no significant differences between post-intervention and follow-up. Larger magnitudes of change in manual dexterity and functional use of the UE were associated with higher initial levels of motor recovery. Findings suggest that a piano-specific training can result in sustainable improvements in UE in persons with a chronic stroke and that those with a higher level of motor recovery at baseline may benefit the most from this intervention.

Keywords: Cerebrovascular Accident, Hand, Hemiparesis, Learning, Music, Rehabilitation
3.2 INTRODUCTION

Up to 85% of persons with stroke experience upper extremity impairments and approximately 50% of community-dwelling stroke individuals experience activity and participation limitations that persist beyond 6 months after stroke onset [1, 2]. Existing approaches for upper extremity rehabilitation have been shown to yield modest to moderate improvements [3], possibly due to insufficient training intensity and lack of adherence to treatment. The current literature on motor learning and recovery indicates that interventions should be meaningful, task-specific, tailored to the person’s capacity and interests, while providing sufficient repetition and challenge to induce training effects [3-8]. Rehabilitation interventions can further take advantage of multi-sensory feedback to provide knowledge of results and/or performance [9].

Music-supported therapy (MST) uses a music learning paradigm to support motor rehabilitation. It is hypothesized that auditory cues may facilitate learning and performance and that the musical context makes the therapy more engaging and rewarding, as compared to conventional approaches. MST has been shown to lead to improvements in fine and gross motor skills in individuals with an acute or a chronic stroke [10, 11]. Electrophysiological and electromagnetic measures further demonstrated that MST may build on auditory-motor coupling mechanisms to drive cortical facilitation and brain plasticity [10, 12]. Despite of the potential of MST for upper extremity rehabilitation, previous studies have not tested whether gains can be maintained on the longer-term. Furthermore, as stroke survivors present with a range of severity, there is a need to determine who can best respond to this intervention. Finally, existing MST programs consist of mixed-instrument protocols (piano and drum pads) that require daily supervised sessions [10, 11]. Such resource intensive protocols may be difficult to implement in the clinical setting or at home. Existing protocols also lack details on training parameters and criteria for progression.

To address these issues, we have developed an individually tailored piano training program that combines structured and supervised training sessions with home practice. The intervention utilizes a user-friendly computerized piano program that does not require note
reading abilities. The primary objective of this study was to estimate the short-term and retention effects of this 3-week piano-specific training program on manual dexterity, finger movement coordination and functional use of upper extremity in persons with chronic stroke. The secondary aim was to provide a detailed description of the training protocol so that it can replicated in the clinical setting.

3.3 METHODOLOGY

3.3.1 Participants

A convenience sample of 13 chronic stroke survivors was recruited among discharged patients of 2 rehabilitation centers in the Montreal area. Inclusion criteria were: 1) first supratentorial chronic stroke (> 6 months) in the middle cerebral artery territory confirmed by CT scan or magnetic resonance imaging; 2) mild to moderate motor deficit of the paretic upper extremity, as reflected by scores of 3 to 6 out of 7 on the arm and hand components of the Chedoke McMaster Stroke Assessment [13] and; 3) ability to follow simple instructions. Participants were also required to have corrected to normal vision and to be free from visual field defect (Goldmann perimetry) [14] and visuospatial neglect (Bell’s test) [15]. Those with moderate to severe cognitive deficits (scores ≤ 23 on the Montreal Cognitive Assessment (MoCA)) [16] or who were currently receiving therapy for the upper extremity were excluded. Those who had severe apraxia, shoulder subluxation or arm pain exacerbated by movement, or any other neurological, neuromuscular or orthopedic condition interfering with upper extremity movements were also excluded. Finally, individuals who had professional musical experience and/or more than 1 hour per week of practice of any musical instrument during the past 10 years were not included in the study. Note that two participants were found \textit{a posteriori} to have a lesion that involved the brainstem (participant #2) and the cerebellum (participant #4). The study was approved by the Ethics Committee of research centre and written informed consent was obtained from each participant.
3.3.2 General procedure

This study involved a multiple pre- multiple post-sequential design. Participants were assessed on clinical outcomes at baseline (week0), pre-intervention (week3), post-intervention (week6) and at follow-up (week9). Although a 3-week follow-up is not ideal to draw conclusions on the long-term effects of the intervention, such follow-up duration was chosen for logistical reasons and it does provide an indication as to whether gains can be maintained once the intervention is completed. All training sessions and evaluations were performed by the same therapist (M.V.) who has a professional background in occupational therapy, a classical piano degree and more than 10 years of piano teaching experience. MV also wrote all musical pieces used in this study. Participants engaged in a step-by-step musical training consisting of three individual 1-hour sessions per week for 3 consecutive weeks, for a total of 9 sessions. Piano performance measures were collected at every session. Supervised sessions were complemented with a biweekly home program (30 minutes) consisting of piano exercises.

3.3.3 Intervention Protocol

Musical pieces, created with Harmony Assistant™, were designed to involve all 5 digits of the paretic hand. Whether played with the right or left hand, they involved the same number of finger repetitions as well as similar finger sequences and melodic patterns. Sound files were exported to Synthesia™, a Musical Instrument Digital Interface (MIDI) piano program that creates a visual display on a computer screen that is adapted for people with no music reading abilities. During the supervised training sessions, the visual display cued the sequence of key presses required to produce each melody by showing a blue dot falling from the upper part of the screen down to indicate the correct key on a virtual keyboard (Figure 1A, 1B). After each cue, the program paused until the participant pressed the correct key before moving on. During the supervised training sessions, participants played on a touch sensitive piano keyboard (Yamaha™ P155). A computer recorded responses from the keyboard and provided a final score indicating the number of errors and duration for each musical piece. During all sessions the therapist provided verbal feedback on the quality of movement and discouraged compensatory strategies (e.g. excessive trunk movements). Home piano exercises were executed on a roll-up flexible piano (Hand Roll Piano, 61K) that was provided to each participant (Figure 1C).
Nine musical pieces were introduced to the participants in an order of increasing difficulty: *level 1* involved movements of consecutive fingers [e.g. 1-2-3-4-5]; *level 2* involved third, fourth, and fifth intervals or movements of nonconsecutive fingers [e.g. 1-3-5-1-4] and; *level 3* involved chords, that is 2 fingers played at the same time. Within each level, 3 musical pieces that involved an increasing number of key presses and changes in melodic direction were introduced (Table 1). In addition, the speed of execution or tempo also increased within each musical piece. For each musical piece, participants started at a tempo of 30 beats per minute (bpm). For each melody, once participants reached ≥80% accuracy (1-(#errors/#key presses) *100) at the target tempo on 3 consecutive trials, the tempo was increased by steps of 10% until reaching a tempo of 60 bpm. After the latter tempo was reached, the next musical piece was introduced. Criteria for progression were inspired by those of a locomotor training study for stroke survivors and modified [17]. During the home practice sessions, participants were asked to reproduce short digit sequences on the roll-up piano. These sequences comprised short excerpts of the same musical pieces practiced during the supervised sessions and consisted in 30 written exercises where all 5 fingers were represented as a number (1=thumb, 5=pinky). Participants reported on their practice duration and content in a logbook after each practice session.

3.3.4 Outcome measures

Changes in participants’ performance were monitored by assessing piano performance and clinical outcome measures. Piano performance measures included the number of errors and duration of the musical pieces recorded with Synthesia, as well as the total number of pieces completed after the 9 sessions. The number of errors reflected both incorrect key presses and early key presses. Note accuracy was calculated as the number or errors divided by the total number of key presses for each musical piece. The total duration recorded by the program reflected the time needed to play an entire musical piece. The MIDI program was designed to
pause until the subject pressed the correct key before moving on and response time (lag between expected response and actual key press) was added to the total duration of the piece.

Clinical measures were collected at baseline, pre- and post-intervention and follow-up. They included the Box and Block Test (BBT), Nine Hole Peg Test (NHPT), Jebsen Hand Function Test, Finger to Nose Test (FTN) and Finger Tapping Test (FTT). The BBT and NHPT were used to evaluate gross and fine manual dexterity, respectively [18, 19]. The functional use of the upper extremity was assessed with the 6-item version of the Jebsen [20]. The FTN and FTT were chosen as measures of arm and finger movement coordination, respectively. For the FTN, participants used their index finger to alternately touch their nose and the therapist’s finger placed approximately 45 cm away and the number of repetitions within 20 seconds was measured. For the FTT, participants tapped their index finger as fast as possible for 15 seconds and the number of repetitions was recorded. The Digit Span, a subtest of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) [21] that assesses auditory recall and working memory, was also evaluated at baseline as an explanatory variable. It was used in this study to examine the effect of musical training on executive functions in stroke individuals, which was shown to have an impact on motor control [22]. Norms for this test are available for older adults [21].

At post-intervention, participant’s comments and observations were collected using a custom-designed questionnaire. The questionnaire included questions where participants rated their interest in the structured piano sessions, the home practice exercises and the musical pieces using a numerical rating scale (score of 0—not interesting and 10=very interesting). Open-ended questions further investigated whether they had experienced adverse or undesirable effects during the intervention, and whether they had observed changes in upper extremity function after the training. Additional written and verbal comments were collected.

3.3.5 Data and statistical analysis

Changes in clinical outcomes at post-intervention and follow-up compared to baseline were first interpreted in the light of the smallest real difference (95% confidence interval) and/or norms for the participants’ age group, when available in the literature. We used a linear mixed
model analysis for repeated measures with autoregressive covariance structure, while controlling for baseline measurements (week₀), with time (pre [week₃], post [week₆] and follow-up [week₉]) as a within-subject factor to assess the effect of the intervention on the different clinical measures. Planned a priori pairwise comparisons were conducted to determine if differences were present between the measurement time-points. To explore whether some of the participants’ characteristics at baseline explained the magnitude of changes observed at post-intervention, correlations were carried out between key outcome measures and characteristics of the participants at baseline, such as age, time since stroke, level of motor recovery (Chedoke McMaster Stroke Assessment), level of manual dexterity (BBT) and auditory recall/working memory status (Digit Span). Pearson correlation coefficients were used for all outcomes, with the exception of the level of motor recovery for which Spearman’s rank correlation coefficients were used. Statistical analyses were performed in SPSS V20. The level of significance was set to p<0.05.

3.4 RESULTS

Five women and 8 men aged between 32 and 79 years (60.1 ± 14.4, mean ± 1SD) participated in the study (Table 2). They had a stroke of embolic or hemorrhagic etiology for a duration that ranged between 6 months and ≈ 9 years at baseline. They presented with a stroke in the right (n=6) or left (n=6) hemisphere. One participant (#4) had a bilateral involvement but predominant damages were observed in the left hemisphere. All participants were right handed and 7 presented with right hand paresis. Based on the arm and hand components of Chedoke McMaster Stroke Assessment, participants were classified as mildly affected (scores of 6, n=7), moderately affected (scores of 4 or 5, n=3) or severely affected (score of 3, n=3). Out of the 13 participants, only 5 had prior musical training, which included 1 to 5 years of non-professional piano experience before the age of 18, with the exception of one participant (#11) who played occasionally (< 1 hour/week) in the 2 years preceding stroke onset but had no formal musical training. Participants were free of cognitive deficits, as indicated by MoCA scores ranging from 28 to 30. All were living in the community and average school attendance was 14 ± 3.7 years (mean ± 1SD).
All participants completed the 9 training sessions over 3 weeks, except participants #3 and #6 who completed the 9 sessions over a 4-week period due to personal constraints. Participants completed 2 to 9 musical pieces during the intervention, such that at the end of the intervention, 4 participants had reached songs of level 1, 5 had reached level 2 and 4 were at level 3 (Table 3). Each piece was practiced on average 25 times before reaching 80% accuracy at 60bpm. When playing at the fastest tempo the average duration for the different musical pieces played by the participants ranged from 32s to 48s. Mean home practice time was 175 min or 28 min/session, with 7 out of the 13 participants reaching or exceeding required practice time (180 min). All participants were able to perform home exercises independently but participants #1 and #2 were instructed to stabilize their paretic wrist with the non-paretic hand to facilitate finger movements.

All participants completed baseline, pre-intervention, post-intervention and follow-up evaluations. Some, however, were unable to complete the NHPT (n=4), the FTN (n=1) and the Jebsen (n=1) at any of the evaluation time points due to their low level of motor recovery. Prior to intervention, no significant differences were found between baseline and pre-intervention scores for any of the clinical tests, including the BBT, NHPT, FTN, FTT and Jebsen (t-tests, p>0.05). Results from the linear mixed model showed significant effects of the intervention (p<0.0001) on the BBT [F(2,24) = 38.70], NHPT [F(2,16) = 17.50], FTN [F(2,22) = 101.59], FTT [F(2,24) = 14.74] and the Jebsen [F(2,21) = 24.02]. Post-hoc analyses revealed that scores were significantly higher at post-intervention compared to pre-intervention (p<0.0001) for the BBT, NHPT, FTN, FTT and the Jebsen, while there was no significant difference between post-intervention and follow-up measurements for any of these measures (p>0.5).

Individual profiles representing actual scores, as well as post- vs. pre-intervention changes on different clinical tests of motor function are shown in Table 3 and Figure 2. Firstly, it can be observed that participants presented with a wide range of scores on the clinical measures prior to the intervention (Figure 2). Secondly, every participant showed improvements on all tests of motor function that were assessed. Thirdly, a large variability in terms of changes in clinical scores was observed across participants (Table 3). In general, larger changes on the BBT were
observed in the mildly affected participants, whereas larger changes on the NHPT and Jebsen were seen in the moderately and severely affected participants. Amongst the 7 participants classified as ‘mildly affected’, many scored within the norms for their age group (mean ± 1SD) at post-intervention on the BBT (n=2), NHPT (n=5) and on all subtests of the Jebsen (n=6) (see norms [18-20, 23]). None of these participants scored within the norms prior to the intervention.

No significant relationships were observed between the magnitude of the changes in the clinical measures of motor function as a result of the intervention (absolute changes between post vs. pre-intervention on the BBT, NHPT, FTN, FTT and Jebsen) and variables such as age, time since stroke, or the performance on the digit span at baseline (r= 0.01 to 0.27, p≥0.3). Participants with larger baseline scores on the BBT presented with larger magnitudes of change between post- vs. pre-intervention on the BBT and Jebsen (r = 0.64 to 0.70, p<0.01), while no significant correlations were found for changes on the NHPT, FTN and FTT (p>0.1). Similarly, those with higher scores on the hand component of the Chedoke McMaster Stroke Assessment showed larger changes between post- vs. pre-intervention on the BBT (r = 0.54, p<0.05) and the Jebsen (r = 0.63, p<0.01), but no significant correlations were observed for other clinical tests (p>0.5). Larger scores on the BBT, NHPT, FTN and FTT at baseline were also found to be associated with longer home practice durations (r = 0.7 to 0.5, p>0.05).

In response to the questionnaire, participants rated their interest in the supervised training session between 8 and 10, while their interest in the musical pieces ranged between 7 and 9. Their interest in the home program received scores that ranged between 2 and 10. Answers to the open-ended questions revealed that 5 participants considered the home training to be less interesting and not as motivating compared to the supervised sessions, due to the lack of feedback received during playing. Six participants reported that the training was good for their mood and motivation to engage in upper extremity exercises, and 11 participants reported that they observed a change in upper extremity function, expressed as an increased mobility of their paretic hand, improvement in fluidity of movements as well as increased coordination and dexterity. More concretely, three participants mentioned that they could pick up small objects more easily and
that they dropped objects less often when using the paretic hand, while 2 participants reported improvements in writing and typing skills. Three participants reported adverse or negative effects, including shoulder stiffness (n=1), fatigue (n=1) and mild hand numbness (n=1), which resolved either immediately or within the hour following the session. Finally, 5 participants expressed the desire to continue piano lessons after their participation in the study; reasons mentioned included the sense of achievement and success (n=2) and the perceived change in motor function and desire to experience further recovery (n=3).

3.5 DISCUSSION

This study examined, for the first time, the short-term and retention effects of a 3-week music-supported therapy program that included supervised sessions and home practice. For this purpose, we have developed a structured program with graded levels and clear criteria for progression, which is amenable to use in clinical setting by rehabilitation therapists who do not have specialized musical training. Gains in upper extremity function were observed in all participants, with larger improvements being observed in those with higher levels of motor recovery at baseline. Gains were maintained 3 weeks after the end of intervention, suggesting that the piano program result in longer-term improvements in upper extremity function.

Our results are consistent with previous research in an acute stroke population where improvements in finger movement coordination, as well as in fine and gross manual dexterity, were reported as a result of a 3-week mixed-instrument (piano and drum pad) MST program [11]. We hypothesize that the significant improvements in gross and fine manual dexterity reflected by changes in the BBT and NHPT in the present study is attributable to the specificity of our piano training program, which targeted dissociated and coordinated finger movements while emphasizing speed of execution and movement accuracy, as well as to intensity of practice sessions and high compliance to the home practice program. The fact that significant changes were also observed in the functional use of the paretic upper extremity in our participants indicates that gains were transferred to functional tasks of daily living such as turning a key, writing, typing, buttoning and tying shoes. Enhancing finger movement coordination may thus be a key element to focus on in upper extremity rehabilitation.
A comparison of our results with those of conventional therapies suggests that MST may compare advantageously. For instance, a mean increase of 7.4 blocks on the BBT was observed in this study, in comparison to mean increases of 4 to 4.5 blocks with constraint-induced movement therapy in people with chronic stroke [24, 25]. Our intervention also required 9 sessions with the therapist and 6 sessions of home practice, as compared to constraint-induced movement therapy that involves intensive arm restriction (3 hours to 90% of waking hours) over a period of 2 to 4 weeks. Our program also relies on user-friendly and commercially available equipment and computer program that can be self-managed and used at home.

Previous studies that have examine the mechanisms behind the effectiveness of MST suggest that improvements in motor function are not merely the result of mass practice of finger movements, but also the results of a cortical reorganization that is mediated through a rapid establishment of auditory-motor coactivation induced by musical training [10, 12, 26, 27]. Melody in itself also represents a powerful source of auditory feedback that provides instantaneous knowledge of the task performance. Hence, both the temporal and spatial features of finger movements can be trained, leading to enhanced movement coordination.

Our findings also reveal the presence of a large variability across participants in terms of initial scores and change scores on the different clinical outcomes as a result of the intervention. Given this variability, additional analyses of individual responses were deemed valuable. One way to do this is to look at the smallest real difference for the BBT (+6 blocks) and the NHPT (-32.8s) [28]. Eight participants exceeded the smallest real difference for the BBT, including mildly, moderately and severely affected participants. Although only 1 participant (moderately affected) reached the smallest real difference for the NHPT (-32.8 s), 5 mildly affected participants reached the norms for their age group. Similarly, 6 mildly affected participants attained the norms on the Jebsen. These observations suggest that a significant proportion of the participants showed a true change in motor recovery. The large proportion of participants in the mildly affected group who showed a true change in manual dexterity and upper extremity use further suggests that the program has the potential to allow participants with minor impairments in motor function to improve their performance up to a level that is within normal limits. The
latter observation is consistent with the fact that participants with mild initial deficits in motor function, as indicated by higher scores on the Chedoke McMaster Stroke Assessment and BBT, were the ones who showed larger gains on most outcome measures, along with longer home practice durations. It cannot be excluded, however, that some of the clinical tests used in this study might not be sensitive enough to detect changes in individuals with more severe deficits in motor recovery. In fact, the NHPT proved to be too difficult to use in 4 participants who were severely or moderately affected, such that changes in fine manual dexterity that might have occurred in these individuals could not be assessed. Changes in FTN and FFT scores, however, reveal that these same participants improved in finger and arm movement coordination, in many instances to an extent that was comparable to changes observed in mildly affected participants. Further, all participants, including the most severely affected ones, were able to complete the program, with no or only minimal assistance. Altogether, these observations support the feasibility of a piano-specific intervention program in chronic stroke survivors presenting with different levels of motor recovery. Findings further indicate that all participants benefited from the training, but that higher initial levels of motor recovery and gross manual dexterity predict larger magnitude of changes on clinical tests of manual dexterity and functional use of upper extremity.

Present findings also revealed that participants enjoyed the training program and felt motivated, especially during the supervised training sessions. Although some participants, due to the absence of feedback, rated the satisfaction towards the home practice content lower, most met or exceeded the requested practice time, suggesting that the intervention triggered a high level of motivation. Some participants further expressed the desire to pursue the piano lessons after the intervention. The sense of achievement and success, the perception of being engaged in a socially valued leisure activity, and the observation of improvements in upper extremity function are factors that may encourage stroke survivors to continue piano training on the long term, such that gains can be maintained and possibly further improved. Although MST should involve minimal risks or disadvantages, these had never been reported in previous studies. In the present study, minor unwanted effects were reported by some participants, including temporary fatigue and arm stiffness/numbness. While these unwanted effects resolved within the hour following the
intervention, it may be advised to closely monitor the level of exertion and other factors such as stiffness or pain in future intervention studies.

The small sample size somewhat limits the generalization of our results, but the current study provides important data to suggest that this standardized MST protocol can be effective for patients of a range of severities. This work was essential to determine the feasibility of a piano-specific training paradigm and to enhance our understanding of which patients respond best to the intervention, before larger clinical trial can be undertaken. The study used only a single therapist, so in the future we plan to train others on the protocol to demonstrate that it can be used by non-specialist personnel. A larger study will also allow us to compare the intervention to a standard treatment. Finally, despite the significant changes observed on all outcome measures, some tests were too difficult for some participants (NHPT) while others possibly showed a ceiling effect (NHPT, Jebsen). In the future, we suggest including more sophisticated techniques such as motion capture to further document changes in inter-finger movement coordination and the presence of compensatory movements. Further work is also needed to investigate the impact of a longer training duration and the longer-term benefits of the training on upper extremity function.

This study provides the first evidence that a piano training intervention combined to home practice can lead to improvements in manual dexterity, finger movement coordination and functional use of the upper extremity that persist 3 weeks after the intervention. In addition to representing a socially valued and enjoyable activity, piano training has the potential to be self-managed and to enable people with chronic stroke to pursue upper extremity exercises beyond the usual rehabilitation time frame.
3.6 ACKNOWLEDGEMENTS

The authors would like to thank all the participants who took part in this study. This project was supported by the Foundation of the Jewish Rehabilitation Hospital. Myriam Villeneuve was the recipient of a scholarship from the School of Physical and Occupational Therapy of McGill University. A Lamontagne holds a Junior 2 Salary Award from FRQS. The authors declare that they have no competing interests.
3.7 REFERENCES


## 3.8 TABLES AND FIGURES

### Table 1. Piece’s Progression

<table>
<thead>
<tr>
<th>Song #</th>
<th>Piece duration (s)*</th>
<th>Number of notes</th>
<th>Number of changes in melodic direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1: Consecutive notes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>52</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>69</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>87</td>
<td>38</td>
</tr>
<tr>
<td><strong>Level 2: Intervals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>59</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>90</td>
<td>40</td>
</tr>
<tr>
<td><strong>Level 3: Chords</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>32</td>
<td>53</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>32</td>
<td>82</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>48</td>
<td>136</td>
<td>31</td>
</tr>
</tbody>
</table>

*Piece duration at 60 bpm
Table 2. Participant Characteristics at Baseline

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Gender</th>
<th>Lesion localization</th>
<th>Etiology</th>
<th>Time since stroke</th>
<th>CMSA arm/hand</th>
<th>Spasticity (MAS)</th>
<th>Musical experience</th>
<th>MoCA score</th>
<th>Digit Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>F</td>
<td>Right basal ganglia</td>
<td>I</td>
<td>118</td>
<td>3/3</td>
<td>3</td>
<td>5</td>
<td>30</td>
<td>11/10</td>
</tr>
<tr>
<td>2</td>
<td>71</td>
<td>F</td>
<td>Left pontine medullary</td>
<td>I</td>
<td>112</td>
<td>3/3</td>
<td>3</td>
<td>0</td>
<td>30</td>
<td>15/8</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>M</td>
<td>Right basal ganglia</td>
<td>I</td>
<td>40</td>
<td>3/3</td>
<td>3</td>
<td>1</td>
<td>30</td>
<td>13/10</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>M</td>
<td>Bilateral cerebellum (L&gt;R) and left thalamus</td>
<td>I</td>
<td>14</td>
<td>4/4</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>12/9</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>M</td>
<td>Left sub-arachnoids and left sylvian fissure</td>
<td>H</td>
<td>32</td>
<td>5/4</td>
<td>1</td>
<td>0</td>
<td>30</td>
<td>11/9</td>
</tr>
<tr>
<td>6</td>
<td>41</td>
<td>M</td>
<td>Right frontal cortex, right basal ganglia, right head of caudate and right corona radiata</td>
<td>I</td>
<td>44</td>
<td>5/4</td>
<td>2</td>
<td>0</td>
<td>30</td>
<td>13/12</td>
</tr>
<tr>
<td>7</td>
<td>75</td>
<td>M</td>
<td>Left frontoparietal region</td>
<td>I</td>
<td>18</td>
<td>6/6</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>14/9</td>
</tr>
<tr>
<td>8</td>
<td>75</td>
<td>M</td>
<td>Right thalamus and internal capsule</td>
<td>H</td>
<td>6</td>
<td>6/6</td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>6/5</td>
</tr>
<tr>
<td>9</td>
<td>74</td>
<td>M</td>
<td>Left Thalamus</td>
<td>I</td>
<td>12</td>
<td>6/6</td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>11/8</td>
</tr>
<tr>
<td>10</td>
<td>79</td>
<td>F</td>
<td>Right sylvian para-central gyrus</td>
<td>I</td>
<td>15</td>
<td>6/6</td>
<td>0</td>
<td>1</td>
<td>30</td>
<td>12/6</td>
</tr>
<tr>
<td>11</td>
<td>60</td>
<td>F</td>
<td>Right intraparenchymal frontal region</td>
<td>H</td>
<td>61</td>
<td>6/6</td>
<td>0</td>
<td>2</td>
<td>30</td>
<td>15/12</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
<td>F</td>
<td>Left intraventricular and left thalamus</td>
<td>H</td>
<td>16</td>
<td>6/6</td>
<td>0</td>
<td>1</td>
<td>28</td>
<td>7/7</td>
</tr>
<tr>
<td>13</td>
<td>57</td>
<td>M</td>
<td>Left posterior limb of internal capsule</td>
<td>I</td>
<td>64</td>
<td>6/6</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>15/10</td>
</tr>
</tbody>
</table>

Age (years), Gender (Male/female), Etiology (Hemorrhagic/Ischemic), Time since stroke (months), CMSA=Chedoke McMaster Stroke Assessment (arm/hand scores, max=7), MAS= Modified Ashworth Scale (max = 5), Musical experience (years), MoCA=Montreal Cognitive Assessment Test (max = 30), Digit Span (forward/ backward scores, max = 16).
Table 3. Changes on Motor Function Tests Post- vs. Pre-Training

<table>
<thead>
<tr>
<th>Participants</th>
<th>BBT</th>
<th>NHPT</th>
<th>FTN</th>
<th>Index FTT</th>
<th>Jebsen</th>
<th>Home Practice Time (min)</th>
<th>Digit Span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Δ</td>
<td>%</td>
<td>Δ</td>
<td>%</td>
<td>Δ</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>SeVERely affected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>200</td>
<td>Ø</td>
<td>Ø</td>
<td>5</td>
<td>100.0</td>
<td>170</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>33.3</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>180‡</td>
</tr>
<tr>
<td>3</td>
<td>7*</td>
<td>50</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>185‡</td>
</tr>
<tr>
<td>Moderately affected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>25</td>
<td>Ø</td>
<td>Ø</td>
<td>1</td>
<td>14.3</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>6*</td>
<td>27.3</td>
<td>-17.7</td>
<td>-15.0</td>
<td>4</td>
<td>36.4</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>14.3</td>
<td>-36.6*</td>
<td>-29.6</td>
<td>7</td>
<td>58.3</td>
<td>135</td>
</tr>
<tr>
<td>Mildly affected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>11*</td>
<td>30.6</td>
<td>-19.4</td>
<td>-40.3</td>
<td>4</td>
<td>25.0</td>
<td>227‡</td>
</tr>
<tr>
<td>8</td>
<td>6*</td>
<td>14.6</td>
<td>-11.9*</td>
<td>-32.2</td>
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<td>31.3</td>
<td>155</td>
</tr>
<tr>
<td>9</td>
<td>10*</td>
<td>28.6</td>
<td>-7.4</td>
<td>-14.0</td>
<td>5</td>
<td>29.4</td>
<td>140</td>
</tr>
<tr>
<td>10</td>
<td>7*</td>
<td>16.3</td>
<td>-9.6*</td>
<td>-28.3</td>
<td>5</td>
<td>35.7</td>
<td>195‡</td>
</tr>
<tr>
<td>11</td>
<td>5*</td>
<td>9.3</td>
<td>-7.1*</td>
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<td>6</td>
<td>23.8</td>
<td>245‡</td>
</tr>
<tr>
<td>12</td>
<td>12*</td>
<td>21.1</td>
<td>-7.1*</td>
<td>-29.2</td>
<td>3</td>
<td>12.5</td>
<td>225‡</td>
</tr>
<tr>
<td>13</td>
<td>17*</td>
<td>32.1</td>
<td>-2.7*</td>
<td>-11.1</td>
<td>7</td>
<td>36.8</td>
<td>315‡</td>
</tr>
<tr>
<td>Mean (sd)</td>
<td>7.4*</td>
<td>38.6</td>
<td>-13.3</td>
<td>-25.1</td>
<td>4.7</td>
<td>35.3</td>
<td>32.4</td>
</tr>
</tbody>
</table>

Δ = Change between pre- and post-intervention
% = Percent change between pre- and post-intervention
Ø = Participant unable to perform the test
* = Participant reached the smallest real difference (SRD) score
† = Participant reached the norms for his/her age group
‡ = Participant practiced at least 180 minutes at home (2x 30 minutes x 3 weeks)
Figure 1. (A) Structured training session setting; (B) Screen shot of Synthesia Musical Instrument Digital Interface (MIDI) piano program; (C) Roll-up flexible piano.
Figure 2. Individual performances for all participants (severely affected [grey solid line], moderately affected [black dashed line], and mildly affected [black solid line]) on the (A) Box and Block Test (BBT); (B) Nine Hole Peg Test (NHPT) and; (C) Jebsen Hand Function Test (Jebsen) at baseline, pre-intervention, post-intervention and follow-up. The area between the vertical dotted lines represents the 3-week intervention period. In (C), the y-axis is discontinued for a better overview of results.
CHAPTER 4: CONCLUSION

The purpose of this thesis was to investigate the feasibility of an individually-tailored, piano-specific training intervention that combines structured piano sessions and home practice in chronic stroke survivors. In Chapter 3, I have presented a study where the short-term and retention effect of a 3-week structured piano-training intervention targeting finger movement coordination on upper extremity function in a chronic stroke population is being investigated for the first time. Results provide preliminary evidence for the effectiveness of the piano program in persons with chronic stroke and supports results from previous research on music-supported therapy. Findings showed that a short piano playing intervention could impact positively on gross and fine manual dexterity, arm and finger coordination, while leading to an improvement of the functional use of the paretic upper extremity. It was shown that piano training could lead to meaningful improvement in upper extremity function in stroke individuals presenting with mild to more severe paresis, without limitation with regard to age and time after stroke. It was further demonstrated that individuals respond differently to the intervention, with a higher initial recovery level leading to larger amounts of change induced by the training.

Present findings also constitute the first evidence supporting the maintenance of training effects at a 3-week follow-up. Maintenance of gains over time is a crucial consideration in stroke rehabilitation and supports the fact that piano playing has the potential to induce plastic changes in the motor cortex of people with chronic stroke. This unique intervention has the potential to be replicated easily, by mean of a detailed description of the intervention protocol, which was presented in the methods section of the manuscript. The operational description of the training parameters and criteria for progression should be useful for future study purposes as well as for implementation of the protocol in a clinical and community setting. The piano training intervention has the potential to be self-managed and continued after cessation of the conventional rehabilitation phase, hence leading to further and sustainable improvements in upper extremity function. Moreover, I demonstrated that participants were highly motivated and engaged actively in piano practice even in the absence of a therapist. This meets one of the challenges in stroke management, which is to offer long-term strategies to promote sustainable changes in motor function after home reintegration. Piano training has the potential to be
delivered as an individually-tailored and effective therapy, which is easy to implement and can be delivered at a lower-cost compared to other solutions (e.g. virtual reality, robotic devices, CIMT), while providing participants with a meaningful activity. As participants reported a sense of achievement and success due to the intervention, it is also possible that the intervention may impact positively on empowerment, mood, and quality of life. These variables could be explored in the context of a future clinical trial, where the piano training intervention could be compared to conventional therapy, or possibly to another intervention involving a mass practice of finger movements without auditory feedback.
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APPENDIX 1: CONSENT FORMS

Consent Form, English Version
Formulaire de Consentement, French Version
INFORMED CONSENT FORM

Research team:
Myriam Villeneuve, B.Sc., erg
Jewish Rehabilitation hospital (JRH)
and
Anouk Lamontagne, Ph.D., pht
JRH and Physical and Occupational therapy school, McGill University

We are asking you to participate in a research project consisting in the evaluation of the effect of a piano training on your arm function. Before agreeing to participate in this project, please take the time to read and carefully consider the following information.

This consent form explains the aim of this study, the procedures, advantages risks and inconvenience as well as the persons to contact, if necessary.

This consent form may contain words that you do not understand. We invite you to ask any question that you deem useful to the researcher and the others members of the staff assigned to the research project and ask them to explain any word or information which is not clear to you.

Introduction:
Following a stroke, several physical deficits may occur, including a decrease in motor control in one of the upper extremities. Then, people who sustained a stoke may have difficulty to use one of their arms during daily activities. As of today, we know that an intensive music training provided in addition to conventional rehabilitation therapy can have a positive impact on the motor recovery of the arm in individuals who sustained a recent stroke. It remains unknown, however, if a piano program alone, which would combine home practices to structured lessons directed by an instructor, would be beneficial.

Objective:
In this project, we will evaluate the impact of a 3-week intensive piano program on fine and gross dexterity as well as function of the paretic upper extremity in individuals who have sustained a stroke since more than 6 months.

Nature of my participation: My participation also involves nine (9) piano training sessions, at the rate of 3 session of 1 hour each week during 3 weeks. During those 3 weeks, I will also be
asked to perform two (2) **home practice** sessions of 30 minutes duration every week. My participation also includes the four (4) **evaluation** sessions of my arm and hand function, which will take place over a period of 9 weeks, starting 3 weeks before and ending 3 weeks after my training program.

The evaluation and training session will take place at the Jewish Rehabilitation Hospital. I shall rest as often as needed throughout the evaluations. A resource person and one of the researchers will be present at any time to greet me and give me assistance.

**Evaluation sessions:**
The evaluations consist in 3 standardized clinical tests:
- Box and Block test (Gross motor evaluation)
- Nine Hole Peg Test (Fine motor evaluation)
- Wolf Motor Function Test (Upper extremity function evaluation)
- Finger-to-Nose Test (motor coordination)
- Finger Tapping Test (motor speed and control)
- Grip and Finger Strength
- Digit Span (working memory)

The evaluation of motor performance will also be recorded throughout a piano program.

**Piano training:**
The training consists in learning and practicing different musical pieces with my affected upper extremity. The training will be done with an electronic piano connected to a computer. **No previous musical experience is required.**

**Home practice:**
The home training program consists in practicing the pieces learned with the instructor, using a flexible-piano that will be provided. I will also be asked to write down the content and duration of my practice sessions.

The following table represents an example of my participation during the training weeks:

<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm-up 15 minutes</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Training 45 minutes</strong></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Home Practice 30 minutes</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Risks and disadvantages:**
Risks associated to my participation in this study are minimal. Traveling from your home to the research site as well as the duration of the session may represent for certain persons a disadvantage. I may experience fatigue following the training. The feeling of fatigue will wear off with rest.

**Benefits:**
Following my participation in the training program, I may or may not observe improvement in my affected upper extremity function. The result of this research will help generate new knowledge and develop better techniques for upper extremity rehabilitation for individuals who have sustained a stroke.

**Financial compensation:**
A financial compensation of 6,50$ per training and evaluation visits will be reimbursed for transportation incurred through my participation in this project.

**Medical record access:**
I understand that information about my health condition will be collected and to that purpose, a member of the research team could consult my medical record. However, only the information related to my stroke will be used.

**Confidentiality:**
Any personal information making it possible to identify me is kept confidential and will be filed in a locked cabinet. The data relating to my evaluations will be transferred onto a computer file server where access is protected by passwords. Only members of the research team have access to the information collected during the project. This information will be preserved for a minimal duration of 5 years, after which they may be destroyed. The data of this research will only be revealed in the form of scientific presentations or publications, without my name or identity exposed.

**Clause of responsibility:**
By accepting to participate in this study, I renounce to none of my rights nor do I release the researchers, backers or the implied institutions from their legal and professional obligations.

**CONSENT:** I can be assured that information that I received concerning this project is exact and complete. My participation in this project is entirely voluntary. My refusal to participate will not affect in any way the treatment that I receive in this hospital. Moreover, I can withdraw from this study at any time.

To obtain an answer to any additional question that I may have concerning this study, I can contact Anouk Lamontagne at (450) 688-9550 poste 531 or by email
(anouk.lamontagne@mcgill.ca). If I have questions about my rights and recourse concerning my participation in this research project, I can communicate with Me Anik Nolet, coordinator of research ethics of the CRIR institutions, at (514) 340-2085 ext 2233 or by email (anolet.crir@ssss.gouv.qc.ca).

My signature here indicates that I have read this form, that I have understood the goal of this research, that this project does not bring me any direct benefits, and that I agree to participate. A copy of this form will be given to me for my own records.

PARTICIPANT NAME SIGNATURE
_________________________ ____________________________

RESEARCHER NAME SIGNATURE
__________________________ ___________________________

Signed at ________________ __________, 20____

Responsible OF THE PRINCIPAL INVESTIGATOR:
I, the undersigned, _________________________ certify that (a) I have explained to the participant the terms of the present agreement, (b) I have responded to all questions posed to me, (c) I have clearly indicated that the participant is free to leave the study described above at any time, and (d) I have provided a signed and dated copy of this consent document to the participant.
FORMULAIRE DE CONSENTEMENT

Chercheurs:
Myriam Villeneuve, B.Sc., erg
Hôpital juif de réadaptation (HJR)
et
Anouk Lamontagne, Ph.D., pt
HJR et École de physiothérapie et d’ergothérapie, Université McGill

Nous vous demandons de participer à un projet de recherche qui consiste à évaluer l’effet d’un entraînement au piano sur la fonction de votre bras. Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements qui suivent.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin.

Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

Introduction:
Suite à un AVC (Accident Vasculaire Cérébral), plusieurs déficits physiques peuvent survenir, dont une diminution du contrôle moteur d’un des membres supérieurs. Ainsi, les personnes ayant subi un AVC peuvent avoir de la difficulté à utiliser l’un des deux bras lors de leurs activités quotidiennes. Nous savons aujourd’hui qu’un entraînement musical intensif combiné à une thérapie de réadaptation conventionnelle peut avoir un effet positif sur la récupération motrice du bras chez les personnes ayant subi un AVC. Toutefois, nous ne savons pas si un programme de piano à lui seul combinant des pratiques à domicile à des pratiques dirigées avec un instructeur pourrait s’avérer bénéfique.

Objectif:
Dans le cadre de ce projet, nous évaluerons l’impact d’un programme de piano intensif de 3 semaines sur la dextérité fine et grossière ainsi que sur la fonction du membre supérieur parétique auprès de personnes ayant subi un AVC depuis plus de 6 mois.
**Nature de ma participation:**
Ma participation comprend neuf (9) sessions d’entraînement au piano, à raison de 3 sessions de 60 minutes par semaine durant 3 semaines. Pendant ces 3 semaines, on me demandera aussi d’effectuer deux (2) pratiques de piano à la maison par semaine d’une durée de 30 minutes. Ma participation comprend aussi quatre (4) sessions d’évaluation d’une durée d’une heure chacune qui se dérouleront sur une période de 9 semaines. Ces évaluations débuteront 3 semaines avant et se termineront 3 semaines après mon programme d’entraînement.

Les évaluations ainsi que les sessions d’entraînement se dérouleront à l’Hôpital Juif de Réadaptation. Je pourrai prendre autant de pause qu’il est nécessaire pendant les évaluations. Une personne-ressource et un des chercheurs de l’équipe seront présents en tout temps afin de m’accueillir et m’aider à me déplacer.

**Session d’évaluation :**
1. Les évaluations consistent en tests standardisés:
2. Box and Block test (Évaluation de la dextérité grossière)
3. Nine Hole Peg Test (Évaluation de la dextérité fine)
4. Wolf Motor Function Test (Évaluation de la fonction du membre supérieur)
5. Test Doigt-Nez (Coordination motrice)
6. «Finger Tapping Test» (Vitesse et Contrôle Moteur)
7. Force musculaire de la main et des doigts
8. Digit Span (Mémoire de travail)

L’évaluation de la performance motrice sera enregistrée directement par le programme de piano.

**Entraînement au piano :**
Préparation: La session d’entraînement sera précédée d’une période d’échauffement et d’étirement de 10 minutes.
L’entraînement consiste à apprendre et pratiquer différentes pièces musicales avec mon membre supérieur atteint. L’entraînement sera fait à l’aide d’un piano électronique branché à un ordinateur. **Aucune expérience musicale n’est requise.**

**Pratique à la maison:**
Durée : 30 minutes
Le programme d’entraînement à la maison consiste à pratiquer les pièces apprises avec l’instructeur à l’aide d’un piano-flexible qui me sera remis. On me demandera aussi d’écrire la durée et le contenu de mes sessions de pratique.
Voici un tableau représentant ma participation durant les 3 semaines d’entraînement:

<table>
<thead>
<tr>
<th></th>
<th>Lundi</th>
<th>Mardi</th>
<th>Mercredi</th>
<th>Jeudi</th>
<th>Vendredi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Échauffement 15 minutes</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Entraînement 45 minutes</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pratique à la maison 30 minutes</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Risques et inconvénients:**
Les risques reliés à ma participation sont minimes. Le déplacement de votre domicile au site de recherche et la durée des sessions d’environ 60 minutes chacune peuvent représenter pour certaines personnes un inconvénient. Je pourrais ressentir une fatigue suite à l’entraînement et, si tel est le cas, cette fatigue se résorbera pendant les périodes de repos.

**Avantages:**
Suite à ma participation au programme d’entraînement, je pourrais ou non observer une amélioration de la fonction de mon membre supérieur atteint. Les résultats de cette étude apporteront aussi des informations qui pourraient aider au développement de meilleures techniques de réadaptation du membre supérieur pour les personnes ayant subi un AVC.

**Indemnité compensatoire:**
Une compensation monétaire de 6,50$ par session d’entraînement et d’évaluation me sera remboursée pour les frais de transport encourus pour ma participation à ce projet.

**Accès au dossier médical:**
Je comprends que des informations sur mon état de santé devront être recueillies et qu’à cette fin, un membre de l’équipe de recherche pourrait consulter mon dossier médical. Cependant, seules les informations se rapportant à mon AVC seront utilisées.

**Confidentialité:**
Toute information personnelle ou permettant de m’identifier est confidentielle et sera gardée sous clef. Les données relatives à ma démarche, qui sont enregistrées à l’aide d’ordinateurs, seront transférées et conservées dans un espace serveur dont l’accès est limité. Seuls les membres de l’équipe de recherche auront accès aux informations recueillies pendant le projet. Si je me retirais du projet, les données de recherche se rapportant à ma participation seraient détruites. Dans le cas contraire, ces informations seront conservées pour une période de 5 ans après la fin du projet, après quoi elles seront détruites. Les données du projet ne seront dévoilées que sous la forme de présentations scientifiques ou de publications, sans que mon nom ou toute autre information pouvant révéler mon identité n’y apparaîsse.
Clause de responsabilité:
En acceptant de participer à cette étude, je ne renonce à aucun de mes droits ni ne libère les chercheurs, le commanditaire ou les institutions impliquées de leurs obligations légales et professionnelles.

CONSENTEMENT: Je peux être assuré(e) que l’information que j’ai reçue concernant ce projet est exacte et complète. Ma participation à ce projet est entièrement volontaire. Mon refus de participer n’affecterait en rien le traitement que je reçois dans cet hôpital. De plus, je pourrai me retirer de cette étude à tout moment.

Pour obtenir réponse à toute question supplémentaire en rapport à cette étude, je pourrai contacter Anouk Lamontagne au (450) 688-9550 poste 531 ou par courriel à l’adresse anouk.lamontagne@mcgill.ca. Si j’ai des questions sur mes droits et recours ou sur ma participation à ce projet de recherche, je pourrai communiquer avec Me Anik Nolet, coordonnatrice à l’éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l’adresse: anolet.crir@ssss.gouv.qc.ca.

Ma signature indique que j’ai lu ce formulaire, que je comprends le but de la recherche et que ce projet ne comporte pas d’avantage personnel, et que j’accepte de participer. Une copie de ce formulaire me sera remise pour mes dossiers.

NOM DU PARTICIPANT                     SIGNATURE
________________________________________  ____________________________

NOM DU CHERCHEUR                      SIGNATURE
________________________________________  ____________________________

Fait à ________________  le__________, 20_______

Engagement du chercheur:

Je, soussigné(e), __________________________, certifie: (a) avoir expliqué au signataire les termes du présent formulaire; (b) avoir répondu aux questions qu’il m’a posées à cet égard; (c) lui avoir clairement indiqué qu’il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus; et (d) que je lui remettrais une copie signée et datée du présent formulaire.
APPENDIX 2: EXAMPLES OF MUSICAL PIECES

A. Level 1: Consecutive notes
B. Level 2: Non-consecutives notes
C. Level 3: Chords
A. Level 1: Consecutive notes

Consecutive no.3 (Right Hand)

Compositeur: Myriam Villeneuve
B. Level 2: Non-consecutives notes

Interval no.6 (Left Hand)

Compositeur : Myriam Villeneuve
C. Level 3: Chords

Chords no. 8 (Right Hand)

Compositeur: Myriam Villeneuve