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Adapting Tai Chi for upper limb rehabilitation post stroke: an exploratory feasibility and efficacy study

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Abstract

Background and Purpose: Tai Chi (TC) has been reported as beneficial for improving balance post stroke, yet its use for upper limb (UL) rehabilitation remains unknown. The purpose of this study was to evaluate the feasibility and efficacy of TC on UL rehabilitation post stroke.

Methods: Twelve chronic stroke survivors with a persistent paresis underwent 60-minute adapted TC sessions twice a week for eight weeks and a 4-week follow-up evaluation. A 10-minute TC home program was recommended for the days without sessions. TC level of performance, adapted movements used, attendance to the sessions and duration of self-practice at home were recorded. Shoulder pain (Visual Analogue Scale (VAS)), motor function of the paretic arm ((Fugl-Meyer Assessment upper-limb section (FMA-UL), Wolf Motor Function Test (WMFT)) and paretic arm use in daily life (Motor Activity Log (MAL)) were measured at baseline, post-treatment and follow-up. A feedback questionnaire was used to evaluate participants' perception of the use of TC at follow-up.

Results: Eleven participants completed the 8-week study. A clinical reasoning algorithm underlying the adaptation of TC was developed based on different functional levels of the participants. Participants with varying profiles including severely impaired UL, poor balance, shoulder pain, and severe spasticity were not only capable of practicing the adapted TC but attended all 16 sessions and practiced TC at home more than recommended (a total of 16.51±9.21 hours). The self-practice amount for subgroups with lower UL function, shoulder pain or moderate-to-severe spasticity, was similar to subgroups with higher functional UL, no shoulder pain, and minimal-to-no spasticity. Participants demonstrated significant improvement over time in the FMA-UL ($p=.009$), WMFT functional scale ($p=.003$), WMFT performance time ($p=.048$) and MAL Amount of Use scale ($p=.02$). Shoulder pain of four participants decreased following TC (VAS 5.5±3, 3±2.8, 2.5±2.5 for the pre, post and follow-up period respectively). Moreover, participants confirmed the usefulness and ease of practicing the adapted TC.

Conclusion: Adapted TC is feasible, acceptable and effective for UL rehabilitation post stroke. Low UL function, insufficient balance, spasticity, and shoulder pain do not seem to hinder practicing TC. Further large-scale randomized trials evaluating TC for UL rehabilitation are warranted.

Keywords: Stroke; rehabilitation; upper extremity; Tai Chi; feasibility; recovery

Résumé

Contexte et objectifs: Le Tai Chi (TC) a été rapporté comme bénéfique pour améliorer l'équilibre suite à un accident vasculaire cérébral (AVC), mais son utilisation pour la réadaptation du membre supérieur reste inconnue. Le but de cette étude était d'évaluer la faisabilité et l'efficacité du TC pour la réadaptation du membre supérieur post-AVC.

Méthode: Douze personnes ayant un AVC en phase chronique avec une parésie persistante ont participé à des sessions de 60 minutes de TC adaptées deux fois par semaine pendant 8 semaines et au suivi à 12 semaines. Un programme à domicile de 10 minutes de TC a été recommandé pour les jours sans session. Le niveau de performance du TC, les mouvements adaptés utilisés, la participation aux sessions et la durée de pratique à domicile ont été documentés. La douleur à l'épaule (Visual Analogue Scale (VAS)), la fonction motrice du bras parétique ((Fugl-Meyer Assessment upper-limb section (FMA-UL), Wolf Motor Function Test (WMFT)) et l'utilisation du bras parétique dans la vie quotidienne (Motor Activity Log (MAL)) ont été mesurées au départ, après le traitement et au suivi (4 semaines post-traitement). Un questionnaire de rétroaction a été utilisé pour évaluer la perception des participants sur l'utilisation du TC lors du suivi.

Résultats: Onze participants ont terminé l'étude de 8 semaines. Un algorithme de raisonnement clinique qui sous-tend l'adaptation du TC a été développé sur la base des niveaux fonctionnels des participants. Les participants ayant des profils différents, y compris le membre supérieur sévèrement atteint, l'équilibre atteint, de la douleur à l'épaule et de la spasticité sévère étaient non seulement capables de pratiquer le TC adapté, mais ont participé à l'ensemble des 16 sessions et pratiquaient le TC à la maison plus que recommandé (un total de 16.51 ± 9.21 heures). La quantité de pratique à domicile des sous-groupes avec la fonction inférieure du membre supérieur, de la douleur à l'épaule ou de la spasticité modérée-à-sévère, était similaire aux sous-groupes avec une fonction supérieure du membre supérieur, sans douleur à l'épaule et une spasticité minimale ou non-présente. Les participants ont montré une amélioration significative au fil du temps selon le FMA -UL (p=.009), l'échelle fonctionnelle du WMFT (p=.003), le temps de performance du WMFT (p=.048) et l'échelle du montant de l'utilisation du MAL (p=.02). La douleur à l'épaule des quatre participants a diminué suite au TC (VAS 5.5±3, 3±2.8, 2.5±2.5

pour la période de pré-traitement, post-traitement et suivi). En outre, les participants ont confirmé l'utilité et la facilité de la pratique du TC adapté.

Conclusion: Le TC adapté est faisable, acceptable et efficace pour la réadaptation du membre supérieur après un AVC. Une fonction diminuée au membre supérieur, l'équilibre insuffisant, la spasticité et la douleur à l'épaule ne semblent pas empêcher la pratique du TC. Plus d'essais randomisés à grande échelle sont nécessaire pour évaluer l'effet du TC sur la réadaptation du membre supérieur.

Mots-clés: Accident vasculaire cérébral; membre supérieur; réadaptation; Tai Chi; faisabilité; récupération motrice

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List of abbreviations

ADL	Activities of daily living
AOU	Amount of Use
BTX	Botulinum toxin
CMSA	Chedoke-McMaster Stroke Assessments
CMSA-arm	Arm stage of Chedoke-McMaster Stroke Assessments
CIMT	Constraint-Induced Movement Therapy
CIRS-G	Severity Index of Cumulative Illness Rating Scale for Geriatrics
FMA-UL	Fugl-Meyer Assessment upper-limb section
Hem	Hemorrhagic stroke
Isc	Ischemic stroke
MAL	Motor Activity Log
MAS	Modified Ashworth Scale
QOM	Quality of Movement
SD	Standard deviation
TC	Tai Chi
UL	Upper limb
VAS	Visual Analogue Scale
WMFT	Wolf Motor Function Test

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Three years ago, I made a big decision to receive a new challenge in my life after having been a doctor in China for more than a decade. There is no doubt that new language, new field, and new environment, were great challenges for me. This intensive period of learning has had a significant impact on me, not only in the scientific field but also on a personal level. I even began to learn Tai Chi and practice Tai Chi until now. The philosophy and wisdom of Tai Chi helped me to face the difficulties calmly and actively, leading me to a new direction in my future life.

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Chapter 1. Introduction

Stroke is a leading cause of serious, long-term disability among middle-aged and older adults worldwide (1). After the age of 55, the risk of having a stroke doubles every ten years (2). Several factors are thought to be important for the long-term prognosis on functional recovery post stroke, including location and size of brain lesion, initial severity of motor impairment, spontaneous recovery capacities and the effects of rehabilitation (3). Active movement practice and repetition are thought to shape neural plasticity and enhance motor recovery. Its frequency and intensity correlate largely with stroke recovery (4). Currently, it is recommended to use rehabilitation programs involving intensive, repetitive, and task-specific movement training to promote motor recovery post stroke (5).

Functional impairment of the upper limb is reported in approximately 85% of stroke survivors and hinders quality of life (6). Upper limb recovery remains one of the most challenging aspects of stroke rehabilitation. Given limited rehabilitation resources, initial therapy post-stroke has tended to concentrate more on improving mobility, ambulation and balance, thus less on upper limb rehabilitation (7). Although recent approaches involving repetitive training of the paretic upper limb using task-oriented activities provide evidence of efficacy for improving upper limb function (8, 9), the beneficial effects of current therapies for arm paresis are shown to be modest (10). At six months after onset, 30-60% of individuals with arm paresis do not recover useful function, and only 5-20% gain full functional recovery of upper limb (11). Nevertheless, upper limb recovery has been shown to continue even after a few years of stroke onset (12), although long-term rehabilitation services are limited to a large proportion of stroke patients (13, 14). Therefore, novel approaches are needed to provide effective and ongoing upper limb rehabilitation and thus reduce the long-term disability from upper limb hemiparesis.

Tai Chi is an ancient martial art originating from Chinese healing traditions. Different from other “external” martial arts, Tai Chi is an “internal” martial art that cultivates the flow and balance of Qi which is also called vital energy (15). Tai Chi is typified by slow and soft movements. Muscle relaxation is thought to be a major feature of Tai Chi involving both the mind and body, facilitating the flow of Qi throughout the whole body (16, 17). To date, Tai Chi is widely accepted as a suitable, low impact, home-based exercise option for the aged and patients with chronic diseases (18-20). Through slow and continuous weight transfer between two feet, Tai Chi has been proven effective to increase muscle strength and flexibility of lower limbs (21, 22). Moreover, it has been shown beneficial for improving balance and for fall prevention in the elderly (23-25).

In recent years, there is some evidence supporting the benefits of Tai Chi in improving balance in chronic stroke patients (26-28). However, no study had reported its use for upper limb rehabilitation post stroke. Tai Chi is a whole-body exercise, and muscle strength and flexibility of the arm have been shown to improve in the aged following Tai Chi (29-31). Furthermore, since muscular relaxation training has been suggested as a means to control involuntary muscular activity (32), the relaxation component of Tai Chi may have the potential to improve spasticity of the paretic upper limb. Therefore, Tai Chi may be a promising upper limb rehabilitation method. However, the presence of hemiparesis may be a significant barrier to using Tai Chi for upper limb rehabilitation post stroke, potentially limiting the ability to perform the Tai Chi upper limb movements. Similarly, shoulder pain and severe spasticity of the affected arm may impact on the capacity to perform Tai Chi movements. Furthermore, the standing position used in traditional Tai Chi styles poses difficulties for persons with poor balance. Although sitting Tai Chi has been reported to be used in individuals with spinal cord injuries to improve muscle strength of upper limb (33), little is known about how to adapt Tai Chi for paretic upper limbs. Modifying Tai Chi to take into account these limitations may need to be considered to include it in post-stroke rehabilitation. Moreover, the feasibility and effect of using adapted Tai Chi movement for upper limb rehabilitation remain unknown.

Therefore, this study aimed to explore the use of adapted Tai Chi movement for upper limb rehabilitation. More specifically, the objective was to evaluate the feasibility and effects of using adapted Tai Chi for upper limb rehabilitation post stroke, including (1) whether the adapted Tai Chi was doable and acceptable by participants; (2) whether the potential influencing factors such as upper limb impairment, insufficient balance, shoulder pain and spasticity constrained the practice of the adapted Tai Chi; (3) whether the adapted Tai Chi was effective in improving motor function of paretic upper limbs and activity of daily living of participants and (4) to document participants' perception of the usefulness and ease of practicing the adapted Tai Chi. A second objective was to document the clinical reasoning underlying the adaptations made to

Tai Chi based on the participants' characteristics when used for upper limb rehabilitation post stroke.

Chapter 2. Literature reviews

2.1 Upper limb rehabilitation post stroke

Stroke, also referred to as cerebrovascular accident, is a disease that affects blood flow to the brain and results in brain damage and loss of brain function. Ischemic and hemorrhagic are two main types of stroke, which lead to improper function of the brain and disability. Hemiparesis is one of the most common impairment after stroke. Functional impairment of the upper limb is reported in approximately 85% of stroke survivors (6), restricting their ability to perform activities of daily living. The long-term functional recovery after stroke usually depends on the initial severity of the attack, natural recovery ability and the effects of rehabilitation (3). However, longitudinal studies of motor recovery after stroke indicate that less than 50% of stroke survivors with significant paresis of upper limb regain functional use (34). Significant impairment of upper limb function post stroke is a common and disturbing problem.

In the following sections, the literature regarding motor recovery from arm paresis after stroke, upper limb rehabilitation interventions, chronic upper limb rehabilitation, rehabilitation for severely impaired upper limb, and evaluating the impact of rehabilitation for upper limb paresis will be presented.

2.1.1 Motor recovery from arm paresis after stroke

Understanding the recovery process from physiological stroke impairments is essential to develop efficacious interventions for stroke rehabilitation. Twitchell first introduced the notion that stroke natural recovery from hemiplegia is a continuous process that follows a stereotyped sequence of events, before reaching a stable status of recovery or disability (35). Afterward, Brunnstrom defined six discrete stages of recovery to describe the sequence of motor recovery. Currently, the Chedoke McMaster Stroke Impairment Inventory with seven stages is the most widely used to describe and assess the stage of motor recovery (36). The pattern of motor recovery post stroke in the upper limb presents several characteristics. First, while the motor recovery in the upper limb follows the same sequence of motor recovery as in the lower limb, it often is at a lower stage of motor recovery than the leg (37). Hence, regaining spontaneous improvement of mobility in the arms is harder than in the lower limbs. Moreover, given limited rehabilitation resources, initial therapy post-stroke has tended to focus more on improving balance, general mobility, and ambulation, thus aggravating the suboptimal outcomes of upper limb rehabilitation (7).

Second, motor recovery follows a sequence from the proximal part to distal part of limbs. Consequently, the stage of recovery of the proximal part of the limbs is often higher than the stage of the distal part. The recovery of the hand (the distal part of an upper limb) is essential for restoration of upper limb function since upper limbs are in charge of fine, well-coordinated and skillful movements. On the other hand, lower limbs are mainly in charge of simple, coarse and semi-automatic movements like walking, which can mostly be fulfilled by hip joints (the proximal part of a lower limb). Therefore, recovery of normal function in the upper limbs may be more difficult and need more time to achieve than regaining lost function in the lower limbs. Furthermore, therapies for the hemiplegic upper limb such as task-oriented approaches usually require a certain recovery of wrist and hand to fulfill tasks or activities, which may further limit the impact of rehabilitation on upper limb recovery.

Thirdly, there are a variety of degrees of spontaneous recovery in upper limb paresis, determined largely by initial severity of paresis and the early patterns of improvement (38). Those who experience early and rapid improvements in motor function post-stroke tend to achieve a much higher level of maximum recovery, while those with a slow recovery at the early stage usually have less successful outcomes (39). Moreover, most of the recovery after a stroke occurs in the first month and reaches a stable status three months after onset (34, 39). Duncan et al. indicated that 86% of the variance in motor recovery at six months could be predicted by assessment scores at one month after stroke (40). Therefore, severity and recovery pattern of arm paresis in the first month after stroke remains strong predictors for long-term consequences (11, 34). These findings suggest that patients with poor prognosis at six months may need novel and intensive rehabilitation.

Fourthly, motor function of the affected upper limb can usually be compensated by the uninvolved upper limb, which may cause secondary impairments such as learned non-use, shoulder pain, spasticity and contracture of joints. Since movements of the affected upper limb are suppressed due to the failure of any activity, learned nonuse results in that stroke patients never learn an existing motor potential and never use the limb (5). Thus, chronic non-use may cause plastic rearrangements in the central nervous system that further reduce the opportunity for motor recovery (41). Such complications may increase the difficulties of upper limb rehabilitation.

2.1.2 Upper limb rehabilitation interventions

2.1.2.1 Effectiveness of interventions

Various stroke rehabilitation techniques for improvement of arm function of stroke survivors have been reported. As compared to traditional rehabilitation methods such as neurodevelopmental techniques which have not been shown to be efficacious (42, 43), more recent treatments including constraint-induced movement therapy, mental practice, electromyographic biofeedback, mirror therapy, virtual reality and robotics give evidence of efficacy in the treatment of arm weakness (10). However, the effectiveness of these rehabilitative interventions varies widely, and evidence is insufficient to enable comparison of the relative effectiveness of interventions because of the heterogeneous mechanisms underlying motor recovery and heterogeneity of trial designs (44). To date, no intervention is recommended as a standard practice owing to lack of high-quality evidence (45). Nevertheless, recent meta-analysis studies supported that treatments comprising intensive, task-oriented, and repetitive training of the paretic upper limb do show evidence for improving motor recovery (9).

2.1.2.2 Intensity of interventions

Active movement practice and repetition are thought to form the basis of motor recovery, with frequency and intensity of movement correlating largely with stroke recovery (4). Interventions characterized by high-intensity properties are thought to be more efficient in improving arm-hand function. It is recommended to provide patients with a certain recovery of arm function every opportunity to practice activities within their ability (46). Additional or enhanced upper limb therapies can be a way to increase frequency and intensity of training and are shown to be effective to improve upper limb function (47, 48). Moreover, self-administered exercise programs by patients during their off-therapy time has been recommended as an efficient way to increase the intensity of treatments (49). However, the efficacy of enhanced therapies is also determined by impairment level of the affected upper limb (12), which may account for the fact that some enhanced therapies did not show significant improvement in upper limb function (50).

2.1.2.3 Evaluating the impact of rehabilitation for upper limb paresis

The choice of outcome measures is essential to assess the efficacy of interventions post-stroke. To date, there are no clear recommendations on which tools are preferred for upper limb outcome measures after stroke. Functional and performance-based tools are usually used to measure the impairments of upper limbs' motor control, such as Fugl-Meyer Assessment, Wolf Motor Function Test, Action Research Arm Test and Chedoke Arm and Hand Activity Inventory which show the excellent clinical utility and high quality of assessment (51). Another type is to measure the disability or use of a paretic arm in real life: activities of daily living (ADL), such as Motor Activity Log and the Barthel index. However, since patients may improve in ADL by compensating with the uninvolved side, only measurements of ADL may be difficult to distinguish real recovery from compensation (52). Therefore, involving different types of measurements is essential to present a full picture of recovery of the paretic upper limb.

Furthermore, since motor recovery in the upper extremity is a slow process, even a small motor change is essential to evaluate a motor rehabilitation approach. Some therapies do improve movement for patients with the severe paresis, however, few assessments are available to accurately measure the upper limb functional gains. Among most of the functional and performance-based measures, only changes of motor control in the Fugl-Meyer Assessment were able to be observed at every stage of sequential motor recovery (53). Its use is warranted in clinical and research contexts. Therefore, there is still a need to develop new outcome measures to discern clinically meaningful but precise motor changes.

2.1.3 Chronic stroke rehabilitation

As mentioned above, motor recovery of arm paresis is a slow and continuous process. Though most cases reached a stable status of recovery or disability at six months after stroke, recent studies showed that chronic stroke patients (more than 6 months) respond to rehabilitation, and improvements can be attained even after a few years of stroke onset (12). Neuroscience studies also support that active practice may facilitate neural plasticity and functional gains even long after spontaneous recovery (54). Therefore, stroke survivors who do not gain significant improvements by six months may require more prolonged and intense periods of rehabilitation. However, limited rehabilitation resources are usually difficult to provide sufficient long-term rehabilitation services. Though it is recommended that patients with moderate or severe stroke should be provide an opportunity to participate in stroke rehabilitation, only 37% of them in Canada were transferred to a rehabilitation facility (55). Those patients who returned home after a stroke still need rehabilitation care services, however, rehabilitation home visits were limited to a large proportion of them (13). Therefore, regular exercise programs for chronic stroke patients at home or in a community are thought to be preferable to solve this problem.

2.1.4 Rehabilitation for severely impaired upper limb

Severely impaired upper limb is a challenge for stroke rehabilitation. Natural motor recovery after stroke occurs more slowly in those severely impaired upper limb (39). Exercising the hemiplegic upper limb is thought to be essential for all stroke patients even at an early stage of motor recovery (12, 46). However, movement practice is dramatically influenced by severity level in the paretic upper limb. Most upper limb interventions require some degree of recovery of the paretic arm to perform movements, thus limiting their use in those with a severely impaired upper limb. For example, task-oriented trainings require that stroke survivors should regain some level of motor function to be able to actively extend the fingers and wrist of the affected upper limb (9). Moreover, secondary impairments caused by primary severely impaired upper limb such as muscle contractures, learned non-use, joint misalignment and pain, can impede the longer-term consequences of upper limb rehabilitation post stroke (5, 56).

Previous studies indicate that there is a global lack of efficacy of interventions in the case of severe motor impairment of the upper limb (57). Kwakkel et al. (58) reported the same rehabilitation intensity resulted in smaller functional gains in the severely paretic arm than in severely paretic leg. Similarly, greater rehabilitation intensity still leads to disappointing results in the case of severely impaired upper limb as compared to moderately impaired upper limb (11). Barecca et al. recommended that for patients with severely impaired upper limbs (Chedoke McMaster score of less than stage 4), treatments should focus on palliation and compensation (59). Hence, to date, treatment approaches for stroke rehabilitation for severely impaired upper limb have still focused mainly on passive movement training or compensatory training of the nonparetic arm (54).

However, the paradigms for rehabilitation interventions for severely impaired upper limb have been challenged. There is some evidence that improvements are observed with the treatment of severe impairment after stroke, although sometimes small. Neurophysiological results suggest that neuronal innervation to muscles remains and restoration of corticospinal activity occurs when stroke patients with severe impairment receive appropriate rehabilitation (60, 61). Brain-controlled robotics, functional electrical stimulation, and mirror therapy have been shown to lead to some improvement for stroke survivors with severe hemiparesis (62, 63).

2.2 Basic concepts of Tai Chi

Tai Chi (also called Taiji, Taiji Quan or Tai Chi Quan) is a martial art originating from ancient China. It is characterized by soft and slow movements, which is dramatically different from other martial arts. As a “soft” martial art, Tai Chi is unique and philosophic. To date, Tai Chi is widely accepted as a suitable, low impact, home-based exercise option for the aged and people with chronic diseases (18-20). Because of its slowness and moderate-intensity, Tai Chi is particularly appreciated by older adults as a way of promoting health. It has grown in popularity throughout the world. Barnes reported that around 2,500,000 individuals in the USA use Tai Chi regularly for medical reasons (64). In order to explore potential benefits of Tai Chi on upper limb rehabilitation post stroke, the core concepts of Tai Chi will be reviewed in the following section, including its history, philosophy, practice features, fundamental principles, and styles and adaptation of Tai Chi.

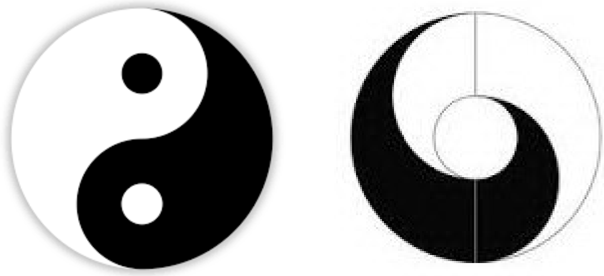
2.2.1 History of Tai Chi

Tai Chi is thought to originate from Taoism. Taoism is a philosophical tradition of Chinese origin that highlights living in harmony with nature and the universe (65). One of the primary goals of Taoism is health and longevity. Since Tai Chi was passed on through inheritance and done in a closed form of master-apprentice succession, the exact historical origin of Tai Chi is still controversial. Zhang Sanfeng (1279-1368 A.D.), a Taoist monk, is credited as having reformed previous martial arts movements to conform to Taoist ideas of softness and yieldingness and thus originated Tai Chi (65). Based on the original note on his manuscript, he mentioned his purpose to create Tai Chi was not only for self-defense but mainly to help practitioners maintain health and increase lifespan (65). Thus, Tai Chi is not only a martial art. It is closely related to Taoism and healing traditions, representing a blending of Chinese martial arts and healing traditions.

2.2.2 Philosophy of Tai Chi

One important consideration to explore the potential medical use of Tai Chi is the way in which such practice is understood within a Taoist context and from a philosophic perspective. The literal translation of Tai Chi is ‘‘Supreme Ultimate’’, a concept of Chinese philosophical meaning, which refers to the original element that makes up the universe and all things (66-68). A state of Supreme Ultimate usually relates to living in harmony with nature and the universe, which is the ultimate goal of Taoism (66). In order to achieve this goal, one must keep oneself in a dynamic balance between Yin and Yang, and live in harmony of mind and body. The Yin-Yang philosophy is a unique way of viewing the world, involving a unity system of the Yin and Yang (17). They are two abstract terms representing the relationships of perceived opposites in the world, which are summarized by the symbols of Tai Chi, by a circle divided into light and dark aspects indicating the constant flow and interaction between Yin and Yang (Figure 1) (69).

Tai Chi is exactly based on Yin-Yang principles by integrating changes of Yin and Yang such as internal and external, dynamics and statics, deficiency and excess, firm and gentle, and fast and slow into Tai Chi movements. Such opposite relations are thought to correspond and interact with each other, to facilitate reaching a balance between Yin and Yang, and finally reaching the state of the Supreme Ultimate (66). Therefore, Tai Chi is in fact a self-cultivation means to realize the state of Supreme Ultimate (17). The whole Tai Chi system and its principles, which will be discussed in the following section, are all for this purpose.



a b

Figure 1. Tai Chi symbols. a. Represents the balance state of Yin and Yang, the black part means Yin and the white means Yang. b. Represents a gradual process of transformation of supreme ultimate and Yin and Yang, the small inner circle means supreme ultimate.

2.2.3 Three stage practice of Tai Chi

In considering the whole system of Tai Chi, Qi and mind are complementary bases of Tai Chi, without which it would become merely a physiological exercise (65, 67). It is hard to define Qi; its English equivalent might be “intrinsic energy.” WT. Chan explained that “Qi denotes the psychophysiological power associated with blood and breath” (67). Tai Chi is not only a martial arts focusing on physical body, but it also combines external movements and intrinsic energy and mind together, to reach harmony of mind and body. More specifically, Tai Chi practice can be described by three stages of practice. The first stage is external or physical movements practice, similar to other general exercises or martial arts. Tai Chi beginners usually belong to this stage. The second stage is Qi exercise. In this stage, Qi can flow smoothly inside coupled with external movements. That is the reason why Tai Chi is also termed as an ‘‘internal” martial art since it cultivates the flow and balance of practitioner’s Qi (15). The third stage is mind practice. In this stage, the mind calms down and is coordinated with Qi and body as a unity. Through learning control over their physical body, Qi, and mind, practitioners finally reach harmony of mind and body. Though these three stages cannot be separated completely, they signify the different level of abilities or attainments which Tai Chi practitioners can reach. In regular Tai Chi training, individuals are usually instructed to relax their muscle and joints in order to promote the flow of Qi. They are required to slow down movements and concentrate on movements for attention training of the mind. Such top-down approaches are thought to be able to help practitioners improve greatly from the first stage practice (67, 70).

2.2.4 Key principles of Tai Chi

In order to perform Tai Chi movements correctly and more efficiently, it is essential to follow its principles. Various Tai Chi manuscripts mention different principles. For example, there are ten fundamental principles of Yang-style Tai Chi, like straightening the head, relaxing the waist, having continuity without interruption, seeking stillness in movement, and having the mind lead the body (71). Among these principles, two are thought to be the key principles, which can mainly summarize other Tai Chi principles. One is relaxation, and the other is coordination.

2.2.4.1 Relaxation

The most important principle of Tai Chi is relaxation when performing movements, termed as "Song" in Chinese. Relaxation means to let the muscles and joints relax and loosen without tension. Its external manifestation is softness of muscles and joints. Many Tai Chi scriptures emphasize the vital importance of relaxation (67, 70, 72, 73). It is thought to be the trademark of a real Tai Chi practitioner. Relaxation makes Tai Chi differ dramatically from other martial arts and exercises that use force through muscle exertion. Through relaxation, physical body in the first stage is loosened, Qi in the second stage flows more fluently inside the body, and the mind in the stage becomes relaxing and peaceful (67).

The muscle relaxation training of Tai Chi is a gradual process. Through continual training, both the range and extent of relaxation will increase progressively. A well-known Tai Chi master, Cheng Man-ching, has described stages of muscle relaxation that Tai Chi practitioners can reach gradually (72). The first stage is muscle relaxation from shoulder to wrist, the second is muscle relaxation from hip joint to ankle, and the third is from trunk to head. Therefore, this suggests that upper limbs may be easier to relax than lower limbs and trunk in the Tai Chi system. The reason may be that upper limbs do not need to support body weight (72). Furthermore, the degree of relaxation increases with more practice (67). For Tai Chi practitioners, they may learn to be aware of tension they carry and to release the tension at the beginning. After they have improved their awareness between tension and relaxation of muscles, they can gradually increase their relaxation.

Apart from muscle relaxation, Tai Chi also emphasizes mind relaxation (74). In Tai Chi theory, physical relaxation alone cannot reach the deep relaxation to relax muscles (72). If practitioners try to force their muscles to relax more, they would in fact conversely increase the tension. Therefore, Tai Chi emphasizes mind-body interaction, using mental relaxation to help to release tension in the body and deepen relaxation level. Practitioners are usually required to clear their mind and concentrate on proper mechanics and movements. Movements are performed slowly to help practitioners focus and relax. Centering or attentional training is thought to be able to allow a person to enter a state of inner peace, promoting mental relaxation (65, 70). Relaxation of body and mind is then mutually infiltrated and promoted since the effects of mind and body are always combined together. Because of emphasis on mind and body relaxation, Tai Chi is also defined as "meditation in motion."

Therefore, Tai Chi relaxation training is different from physical relaxation training techniques that focus merely on releasing muscle tension. Apart from focusing on relaxing muscles, Tai Chi emphasizes attentional training to help deepen relaxation of the body. To date Tai Chi relaxation training was reported to have beneficial effects on mental health, depression and stress reduction in various populations (16, 75), although no studies have focused on the effects of Tai Chi relaxation on motor function improvements.

2.2.4.2 Coordination

The second important principle of Tai Chi is coordination, which means all parts of the body move in harmony. Tai Chi requires the entire body move as a whole unit by practicing sequential motions in a semi-squat posture, and using the waist as the center or axis to direct the movements of upper and lower limbs (Figure 2) (76). Movements begin in the feet, transfer a counterforce rooting from the earth from legs to trunk, and then from trunk to shoulders, finally to hands. Weight shifting, trunk rotation and upper limb movements are thus combined together. As mentioned previously, based on Yin-Yang principle, Tai Chi integrates changes of Yin and Yang into Tai Chi movements. With respect to upper limb movements, Tai Chi requires both upper limbs to move simultaneously, however, the bilateral movements of the upper limbs are different (i.e. the arm movements performed by each arm are different). Generally, one side represents Yin, and the other side represents Yang. This type of upper limb movement may require more bilateral coordination than those upper limb movements which are the same.

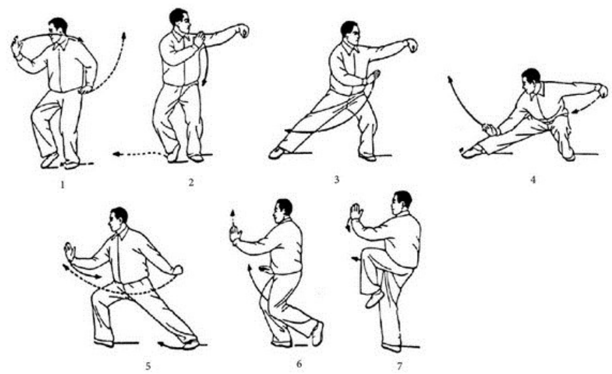


Figure 2. A traditional Tai Chi form. The sequential motions require coordination of the whole body.

2.2.4.3 The relationship between relaxation and coordination

Relaxation is thought to be the key principle of Tai Chi. The entire body must be relaxed so that it can move as one complete unit without obstruction. Without relaxation, even well-coordinated movements are still considered to be a general exercise in Tai Chi (65). On the basis of relaxation, coordination is thought to be a higher level skill which can make Qi circulate better and guide Qi for applications. Without coordination, the promotion of Qi and blood circulation of Tai Chi may decrease. Understanding the relationship between relaxation and coordination, can help teaching and adapting Tai Chi for people with different physical functions.

2.2.5 Styles and adaptation of Tai Chi

There are five major traditional styles of Tai Chi, including Yang, Cheng, Wu, Wu (Hao) and Sun styles which were named after their founders. In fact, the presence of diverse styles is the result of the adaptation of Tai Chi since founders of Tai Chi styles have adjusted original Tai Chi forms to comply with their own needs. Each style has its own forms and characteristics. As the most popular style throughout the world, the Yang style is gentle and graceful with slow, steady movements, emphasizing relaxation and yielding to force (77). It is easy for practitioners to follow Yang-style Tai Chi movements without efforts. Because of its slow and soft movements, Yang-style Tai Chi is widely used in the elderly and people with chronic diseases (78, 79). A systematic review indicated that most Tai Chi studies in older adults used modified versions of Yang style as an intervention (79). However, all styles conform to the same principles and retain their original martial arts applications. Practitioners usually choose styles or forms based on their own needs.

Nevertheless, these traditional styles were developed to meet combat demands, so some of the forms are not necessarily desirable for health and therapeutic outcomes. Several forms from the Yang style even involve deep squat postures, which pose difficulties for frail older adults and individuals with physical disabilities. Thus, traditional Tai Chi forms have been adapted into simpler and more practical ones for targeted populations. Among the adapted Tai Chi forms reported from recent clinical trials, most of them are short forms directly selected from traditional styles (16, 28, 80). These modified short forms, varying from 5 to 24 forms, are suitable for the aged and person with a chronic disease such as diabetes and cardiovascular disease (79). However, they are still challenging for individuals with disabilities. Hence, it is necessary to adapt Tai Chi forms into more adaptable movements for individuals with disabilities. However, little information has been provided in the previous studies about how to adapt Tai Chi movements for the disabled.

2.3 Effect of Tai Chi on the neuromuscular system

A growing number of studies have reported health benefits of Tai Chi. Since this study will explore the potential effects of Tai Chi post stroke, previous studies of Tai Chi focusing on the neuromuscular system will be mainly reviewed.

2.3.1 Effects of Tai Chi on lower limb and balance in the aged

As a low-impact exercise, the effects of Tai Chi on the neuromuscular system in the elderly have been widely reported. Most Tai Chi studies that have looked at the neuromuscular system have focused on lower limbs and balance. As a martial art, Tai Chi forms involve slow and consistent weight shifting between two feet and single-leg standing in different positions. Tai Chi has been proven effective in increasing muscle strength of the lower limbs (21, 22, 81). Moreover, Tai Chi requires the coordination of different parts of the body during motions and has been shown beneficial in increasing lower limb and thoracolumbar flexibility (82, 83). Tai Chi practitioners have also been shown to have better proprioception at the lower limb joints than control groups (84).

Apart from the lower limb muscular system, a number of studies reported the effectiveness of Tai Chi in improving balance in the aged (23-25). Through recordings of the center of pressure during gait initiation, Chris J. Hass reported that Tai Chi training emphasizes interlimb coordination by transferring the body weight between the legs, which may lead to increased movement smoothness and improve coordination and postural control ability (85). The effectiveness of Tai Chi on reducing the rate of falls and the risk of falling have also been shown (86, 87). In a randomized control trial with a total of 200 participants, Tai Chi groups delayed the occurrence of the first fall by 47.5% and improved postural stability in the elderly compared with the two controls groups (88). Voukelatos et al. (89) also reported that 702 older adults showed significantly less falls than the control group after having participated in a 16-week Tai Chi exercise program. These findings suggest that Tai Chi has a positive impact on falls prevention and balance function and in older adults.

2.3.2 Effects of Tai Chi on upper limb in the aged

Compared with the significant body of literature regarding lower limb and balance, a much smaller number of studies have examined the effects of Tai Chi on upper limb. The reason may be that balance and fall prevention are more prevalent issues than upper limb function improvement in the aged population. There is evidence that Tai Chi can improve overall grip strength of upper limb in older adults (21, 90), and arm flexor strength as well as overall upper limb strength assessed with arm curl test (21, 91). Several studies have reported that Tai Chi could improve the eye-hand coordination in the elderly by attaining better accuracy on finger pointing tasks (30, 92, 93), and could improve movement control of upper limb on functional standing-reaching tasks (31). Tai Chi practitioners have also been demonstrated better shoulder kinesthetic sense after a 12-week Tai Chi program (94). Besides, eight weeks of Tai Chi practice significantly improved force variability of manual aiming movements as compared to participants in a locomotor activity group and shows that ability for daily activities can be enhanced through Tai Chi (95).

2.3.3 Intensity and safety of Tai Chi

The slowness and softness make Tai Chi a low impact exercise, suitable for people in different physical situations. Though traditional Tai Chi forms are practiced in a semi-squat posture, Tai Chi practitioners can adjust the angle of the knee for the proper exercise intensity. During Tai Chi practice, the oxygen uptake and heart rate were shown to be only 55% and 58% of the heart rate range and maximal oxygen uptake (96), which implies Tai Chi is an aerobic exercise with moderate intensity. Moreover, exercise intensity of Tai Chi was shown similar across Tai Chi practitioners with different ages (97). Though there are significant differences in Tai Chi training protocols of previous studies, most Tai Chi exercise program lasted larger or equal to 12 weeks, and each session lasted 40 to 90 minutes. Since the inconsistency of the exercise intensity and amount during the initial period of learning movements, the recommended Tai Chi program is at least six months of training, and the recommended duration of each Tai Chi training session is 40 to 60 minutes (16). Some Tai Chi programs recommend that participants practice Tai Chi at home apart from the Tai Chi sessions (98, 99), which is thought to be a way to help Tai Chi novices be able to practice Tai Chi more efficiently within a short period.

Moreover, slowness and relaxation makes Tai Chi a highly safe exercise. Since the burden of Tai Chi to respiratory and circulatory systems is light, Tai Chi has even been safely performed by patients with chronic obstructive pulmonary disease and chronic heart failure (100, 101). A systematic review of adverse events with Tai Chi reported that no severe adverse events were found except minor musculoskeletal pains at the beginning (e.g. knee and back pain) (102). The high safety makes Tai Chi a suitable home-based or community-based exercise without supervision (103-105).

2.3.4 Underlying mechanism of Tai Chi health benefits

The fact that Tai Chi movements can promote muscle strength, flexibility, postural stability and proprioception of the lower limbs, may be the reason for Tai Chi's effectiveness for improving balance and preventing falls (16, 84, 85). Apart from the neuromuscular system, recent studies have also reported the beneficial therapeutic effects of Tai Chi on cardiovascular, pulmonary, rheumatological and orthopedic diseases (16, 106). However, concerning the biological mechanisms leading to improvement, there is a lack of reliable scientific evidence on most Tai

Chi indications (106). A systematic review and meta-analysis suggested that aerobic capacity of subjects in Tai Chi exercise groups were significantly increased as compared to sedentary subjects (107). Improving aerobic capacity of the whole body may be one of the mechanisms underlying Tai Chi's benefits on the cardiovascular and pulmonary systems. Based on Chinese healing tradition, health benefits of Tai Chi are regarded as originating from better Qi circulation. "Qi" as a vital energy force which flows through the body and is thought to be essential to health. The disorder of Qi is believed to be the origin of illnesses (108). Relaxation and coordination of Tai Chi movements are considered to cultivates the flow and balance of practitioner's Qi in the body, thus producing health benefits (15).

2.4 Research regarding Tai Chi for stroke rehabilitation

2.4.1 Research regarding Tai Chi for improving balance and preventing falls post stroke

In recent years, there is some evidence supporting the benefits of Tai Chi in improving balance in chronic stroke patients (26-28). Two 12-week Tai Chi programs have been shown to be safe, feasible and to have good compliance for chronic stroke survivors (80, 109). Stephanie et al. reported that a 12-week short-form Tai Chi program improved balance of 74 chronic stroke survivors with an average five years of stroke onset (28). Furthermore, a randomized controlled trial indicated that a 12-week Yang style short form Tai Chi was more effective in reducing fall rates than general exercises groups in stroke survivors with an average three years of stroke onset (26). However, the samples in these studies were all chronic stroke patients, no studies have focused on the recovery phase less than two years post stroke. Furthermore, these studies recruited participants who have a certain recovery of balance capacity (e.g. individuals with ability to walk at least six meters) (28), or screened patients for safety using standardized tests to assess functional disability prior to study enrollment (26), since balance training for stroke survivors used standing Tai Chi positions which requires sufficient balance to support standing. This limitation constrains the use of Tai Chi on balance rehabilitation post stroke. Future studies which include stroke patients of varying degrees of disability to investigate the comprehensive effect of Tai Chi for balance training after stroke are warranted.

2.4.2 Research regarding Tai Chi for upper limb rehabilitation post stroke

To date no study has reported the use of Tai Chi for upper limb rehabilitation post stroke. The feasibility and effectiveness of Tai Chi on the paretic upper limb remain unknown. However, Tai Chi may be promising to be used for upper limb rehabilitation for the following reasons. First, Tai Chi is not only an exercise of lower limb but a whole-body exercise, though leading health benefits of Tai Chi have been reported by muscle strengthening of lower limb, improving balance and prevention of falls. Nevertheless, muscle strength and flexibility of upper limb have also been shown to increase in the aged following Tai Chi intervention (29-31). Second, muscle relaxation training has been suggested as a means to control involuntary muscular activity (32, 110), the relaxation component of Tai Chi may therefore have the potential to improve spasticity of paretic upper limb after stroke. As previously mentioned, upper limbs are easier to relax than lower limbs because upper limbs do not need to support the body weight (72) . Hence, relaxation on upper limb may be feasible and effective to reduce spasticity and improve motor control of paretic upper limbs. Third, Tai Chi is a safe and home-based rehabilitation, highly acceptable by community-dwelling aged people, which may provide an ideal choice for stroke survivors as an ongoing and self-administered rehabilitation technique. Therefore, Tai Chi may be a promising upper limb rehabilitation method.

2.5 Comparing upper limb rehabilitation therapies to Tai Chi

In the following section, the use of several upper limb rehabilitation therapies will be reviewed. In addition, the similarities and differences between these therapies and Tai Chi will be discussed. Traditional Tai Chi forms involve movements of both upper limbs, therefore, constraint-induced movement therapy and bilateral arm training may use similar principles as Tai Chi. Moreover, Tai Chi includes trunk movements, an important component of the trunk restraint therapy approach. Third, given that Tai Chi belongs to mind-body interventions, mind-body therapies used for upper limb rehabilitation after stroke will also be reviewed.

2.5.1 Constraint-Induced Movement Therapy

The premise of Constraint-Induced Movement Therapy is to require intensive training of the paretic arm and constrain movements of the non-paretic limb, in order to reverse additional impairment caused by learned non-use (5). Randomized controlled studies have shown that with forced use of the paretic upper limb in task-specific activities, patients have made significant and lasting functional gains in functional capacity and daily use (111). These findings support the hypothesis that patients have "learned non-use" of their paretic limb and that the forced use of intensive training techniques, activates the neuromuscular pathways (5, 112). CIMT produces a variable outcome that relies not only on the techniques and training intensity of the force use, but the severity of initial impairment of the paretic upper limb. In general, individuals with less impaired upper limb tend to gain more than those with severe impairment (112). However, CIMT is recommended for people who have at least some recovery of the hand, and CIMT requires great commitment from the patient and considerable health resources, which thus limits its use in stroke rehabilitation (46).

Based on traditional Tai Chi forms, Tai Chi upper limb movements are performed both sides together. Since the purpose of upper limb rehabilitation post stroke is to improve motor function of the paretic upper limb, upper limb movements of Tai Chi may be adapted from bilateral practice to the practice of only paretic upper limb. However, to keep bilateral upper limb movements of Tai Chi may be a better way to maintain the original characteristics of Tai Chi (113), and thus explore better the potential use of Tai Chi for upper limb rehabilitation. Compared with CIMT which emphasizes intensive training of the paretic arm by constraining movements of the nonparetic limb, whether bilateral upper limb movements of Tai Chi are feasible and effective for upper limb rehabilitation post stroke, remains to be explored.

2.5.2 Bilateral arm training

The use of bilateral upper limb training has been proposed as a strategy for upper limb rehabilitation based on the assumption that the utilization of the uninvolved limb may facilitate interlimb coupling effect and thus promote motor recovery of the involved limb (46, 114). Different from unilateral arm training, bilateral arm training requires both upper limbs to practice symmetrical or asymmetrical movements simultaneously. Symmetrical movements mean that both arms perform the same movement pattern, and asymmetrical movements mean that one hand complements the other, using differentiated limb patterns (115).

A systematic review which included the results from 11 controlled trials, reported that bilateral training is effective in improving hemiplegic upper limb control during the sub-acute and chronic phases of stroke recovery, with a relatively large overall effect size of 0.732 (116). Another systematic review of nine studies in the chronic stage of stroke also reported the benefits of bilateral training in improving functional recovery of the paretic arm with the Fugl-Meyer Assessment and time component of the Wolf Motor Function Test (117). However, there is still conflicting evidence that bilateral arm training is superior to unilateral training. Morris et al. found that bilateral training may be no more effective than unilateral arm training (114). A meta-analysis of nine randomized controlled trials involving 452 patients reported that the effects of bilateral and unilateral training are similar. However, bilateral training may be more preferentially used in the case of moderate to severe arm impairment, whereas unilateral training may be more suitable for mild arm impairment (118).

Given the heterogeneity of stroke (size and location of the lesion, type of stroke, initial severity of hemiparesis) and design of trials, it may be difficult to conclude the superiority of bilateral or unilateral arm training. However, bilateral arm training may improve bimanual coordination of upper limbs, considering that upper limb paresis impacts the ability of many stroke patients to use the affected hand to perform bimanual tasks in daily activities (119). Waller et al. suggested that both bilateral and unilateral arm training appear necessary for stroke rehabilitation, unilateral arm training techniques should not be the only or the primary focus in particular for those with non-dominant paresis (115).

Tai Chi upper limb movements also require bilateral arm movements. However, most of Tai Chi upper limb movements are different between the two arms (i.e. the arm movements performed by each side were different), which may require more bilateral coordination than other bilateral arm training techniques, particularly for stroke patients with severe to moderate arm paresis. Therefore, as opposed to what Van Delden has proposed above (118), unilateral Tai Chi movements may be feasible and preferential for moderate to severe arm paresis, whereas bilateral Tai Chi movements may be practical for mild arm paresis. However, the feasibility and effectiveness of Tai Chi bilateral upper limb movements used for upper limb rehabilitation remains to be shown, including whether bilateral Tai Chi upper limb movements are feasible for stroke survivors with the hemiplegic upper limb, the impact of the impairment level of upper limb on practicing bilateral movements, and the effectiveness of practicing bilateral Tai Chi movements.

2.5.3 Trunk restraint therapy

Compensatory trunk movements often occur when stroke patients with moderate to severe arm impairment use the affected arm to reach for objects placed within reach of the arm. Usually achieved through a chest harness and combined with task-specific techniques, trunk restraint therapy is thought to be able to encourage the recovery of normal reaching patterns and function of the paretic arm by restraining the trunk movements. It has been shown beneficial in improving dissociation between the trunk and upper limb, and in increasing shoulder flexion and abduction post stroke (120). A systematic review of six randomized controlled trials suggested that trunk restraint therapy improved the performance of reach trajectories in stroke patients and its effect in improving upper limb function was moderate (121).

Tai Chi involves movements of the whole body in a well-coordinated way (76). Movements begin in the feet, transfer a counterforce rooting from the ground from legs to the trunk, and then from the trunk to the shoulders, finally to the hands. Through these type of movements, weight shifting, trunk rotation, and hand push are performed sequentially. When practicing Tai Chi movements, trunk rotation, and upper limb movements need to be separated. Thus, Tai Chi could be considered to be a kind of trunk restraint exercise without the use of an external device, which may be helpful to improve normalized reaching patterns and upper limb function. However, to date, no studies have reported its use as a trunk restraint technique for upper limb rehabilitation. Since trunk movements in Tai Chi are performed without the help of an external device, whether it could be used by stroke survivors, particularly by stroke patients with severely impaired upper limb, raises an issue. Its feasibility and efficacy used for upper limb rehabilitation remain to be explored.

2.5.4 Mind-body therapies and biofeedback

Mind-body therapies cover various techniques that enable practitioners to use the mental capacity to improve their physical health, including hypnosis, meditation, Tai Chi, yoga, biofeedback, Qigong and visual imagery and so on (122). They focus on the connections between the mind and body, and the impact of mental capacity on health and disease, mainly emphasizing both mind and body relaxation (122). These therapies are often implemented by patients because patients are allowed to play a more active role in their health and disease. Because of their feature of relaxation, mind-body therapies have been reported effective in improving psychosocial function post stroke (123, 124). However, aside from biofeedback, few mind-body therapies have been indicated for use in improving motor recovery post stroke.

As a technique to help muscle relaxation, biofeedback has been advocated as a useful adjunct to conventional physical treatments for stroke. This method uses specialized instruments to monitor electrical potentials that accompany muscle contraction and provides the patient an indication of the level of muscle relaxation (125). In a randomized controlled trial with 40 stroke patients, Dogan-Aslan et al. reported the benefit of biofeedback in improving the function of the paretic upper limb (126). However, a systematic review compared the efficacy of biofeedback and conventional physical therapy for upper limb functional recovery post stroke, and indicated that biofeedback was not superior to conventional physical therapy (127). Moreover, some factors such as ease of access and use, cost, and patient preferences influence the application of biofeedback for upper limb rehabilitation post stroke (125).

Tai Chi is a type of mind-body intervention and is also known as "meditation in motion." Tai Chi emphasizes mind-body interaction and enables practitioners to use the mental capacity to influence the physical movements and function, to finally reach a perfect harmony and balance between the body and the mind (74). However, the effect of Tai Chi for upper limb rehabilitation remains unknown.

2.6 Potential barriers regarding Tai Chi used for upper limb rehabilitation post stroke

In the following section, several stroke impairments which may influence the use of Tai Chi for upper limb rehabilitation will be discussed, including hemiparesis, spasticity and shoulder pain.

2.6.1 Hemiparesis

The presence of the paretic upper limb may be a barrier to using Tai Chi for upper limb rehabilitation, potentially limiting the ability to perform the Tai Chi upper limb movements. The extent to which Tai-Chi can be used with individuals with a severe upper limb hemiparesis and its impact on recovery remain unknown. Furthermore, the standing position used in traditional Tai Chi styles poses a challenge for persons with insufficient balance after stroke. Therefore, to use Tai Chi for upper limb post-stroke rehabilitation, Tai Chi needs to be adapted for stroke survivors, and this may vary according to different impairment levels of the hemiparesis.

For participants with poor balance, sitting Tai Chi (also called seated Tai Chi, wheelchair Tai Chi) might be a solution, though it has never been documented for stroke rehabilitation. Sitting Tai Chi refers to practicing Tai Chi movements in a sitting position, focusing only on trunk and upper limb movements. It has been developed for persons with ambulatory dysfunction such as insufficient standing and balance abilities to practice Tai Chi (33, 128). Sitting Tai Chi has been proved to be effective in improving sitting balance and upper limb function. Leung et al. indicated that sitting Tai Chi forms improved the sitting balance of the frail elderly who had difficulty in taking a standing position (129). Moreover, several studies have reported the effectiveness of sitting Tai Chi on upper limb. Lee et al. reported that three months of sitting Tai Chi exercise program had significantly improved the maximum reaching distance and accuracy in finger-pointing tasks (eye-hand coordination) in the elderly (130). William et al. indicated that sitting Tai Chi led to increased handgrip strength in patients with a spinal cord injury (33). A 15-week sitting Tai Chi program showed significant improvements in extension and external rotation extension of the shoulder joint among sedentary individuals with lower-limb disabilities (29). No study has examined the use of sitting Tai Chi on stroke rehabilitation. How to choose lower limb positions of Tai Chi based on different level of balance, and whether practicing Tai Chi with a sitting position will influence the effects of Tai Chi on the paretic upper limb, remain to be explored.

For participants with severely impaired upper limb, upper limb movements of Tai Chi may need to be adapted into more suitable forms to allow them to practice Tai Chi. However, apart from sitting Tai Chi, few studies have reported how to modify Tai Chi for the disabled, in particular for patients with upper-limb disabilities. One reason may be that most of the studies did not present detailed training protocols and details of how they adapted Tai Chi in their studies. Fuzhong et al. suggest that to explore therapeutic potentials of Tai Chi in different populations, adapted Tai Chi forms are warranted to adjust movements for functional activities and to optimize individuals' inherent control capacity (113). Furthermore, as mentioned above, to ensure the originality and effectiveness of adapted Tai Chi, it is important to follow the fundamental principles of Tai Chi. Therefore, when adapting Tai Chi for persons with upper-limb disabilities it may be essential to 1) develop specific movements to adjust upper limb impairments; 2) follow the key principles of Tai Chi; 3) challenge practitioners by gradually increasing the practice difficulty

2.6.2 Spasticity

Spasticity has been defined as "a motor disorder characterized by a velocity-dependent increase in muscle tone, resulting from hyperexcitability of the stretch reflex" (131). It occurs in 20%-30% of all stroke survivors and 42.6% of those with paresis, and it is more common in the upper than the lower limbs, especially severe spasticity (Modified Ashworth Scale 3) was observed more often in the muscles of upper limb (132, 133). The Modified Ashworth Scale, which measures the level of resistance during passive soft-tissue stretching, is the most common used clinical assessment of spasticity after stroke (134). However, one limitation of the MAS is that it cannot differentiate the resistance to passive movement is due to a hyperactive stretch reflex or contracture of the joint (135). Spasticity is associated with greater impairment and poor function and may impede rehabilitation. It may also lead to resistance to Tai Chi movements and influence the use of Tai Chi for upper limb rehabilitation post stroke. Thus, apart from hemiparesis, spasticity may need to be taken into account when adapting Tai Chi. Moreover, the extent to which Tai-Chi can be used with individuals with spasticity remains unknown.

The treatment of spasticity includes a variety of approaches, varying from conservative to more aggressive therapies. Though physical therapy interventions such as passive muscle stretching, positioning, and range-of-motion exercise are helpful in spasticity reduction and thus play a major role in the treatment of spasticity, there is no reliable evidence comparing the efficacy between different physical therapies (136). Though based on the idea that spasticity interferes with normal motor functioning, Bobath technique is supported only by some evidence that it can efficiently reduce spasticity in stroke patients (137). Task-specific approaches, such a CIMT, seem to have better effects in reducing spasticity after stroke rather than neurodevelopmental approaches (132). Overall, except for botulinum toxin injections, there is a lack of scientific guidelines regarding the choice of different treatments for spasticity after stroke (135).

Muscle relaxation training has been suggested as a means to control the involuntary muscular activity of cerebral palsy patients (32). Jacobson's Progressive Muscle Relaxation is a self-management relaxation technique facilitating practitioners to detect and reduce muscles tension of the body deliberately, has been reported to be effective in the treatment of spasticity in cerebral palsy patients (32, 110). However, progressive muscle relaxation has never been stated to be used for reducing spasticity of stroke survivors. As mentioned above, mind-body therapies emphasize mind relation as well as muscle relaxation. Though biofeedback can help muscle relaxation and promote movements patterns with the utilization of external measuring devices, few studies have focused its use in the treatment of spasticity. The effect of Tai Chi on spasticity, a mind-body therapy, has not been reported in previous studies. In this exploratory study, it is interesting to investigate whether and how spasticity impacts the Tai Chi practice, and whether the relaxation component of Tai Chi can reduce spasticity of the upper limb and improve motor control of upper limb.

2.6.3 Shoulder pain

Similarly, hemiplegic shoulder pain is a complicated sequela of stroke that is commonly associated with the paretic upper limb. The incidence of this complication varies from 12% to 58% depending on the patient group and study design (138). It can be present at any stage of the stroke. Shoulder pain can hinder rehabilitation of hemiparesis and delay functional recovery (56). Though the precise etiology of this problem is still controversial, several factors have been suggested that they may be related to hemiplegic shoulder pain including paralysis, restricted shoulder morbidity, shoulder subluxation, frozen shoulder, spasticity, sensory abnormalities, and improper handling of the patient (138, 139).

The vigorous range of motion of the involved upper limb may also cause the onset of shoulder pain from the pathological shoulder. For example, overhead pulleys are thought to be easy to develop shoulder pain, thus should be avoided to use during range of motion exercises (140, 141). Moreover, the external rotators are muscles commonly involved in different shoulder pathologies. The range of lateral shoulder rotation is considered as the most significant factor related to the occurrence of shoulder pain (140). Nevertheless, emphasis on external shoulder rotation and abduction stretching are recommended as part of rehabilitation to prevent the occurrence of shoulder pain and treat shoulder pain (8, 142).

Hence, to design an exercise program for upper limb rehabilitation is important to take into account range of motion related to shoulder pain. The role that pain plays in using Tai Chi for rehabilitation is not known. Given that Tai Chi includes movements conducted with shoulder movement, it is unknown whether shoulder pain may occur or increase during Tai Chi practice, thus impeding Tai Chi movements, or on the contrary, if the Tai Chi movements may be helpful to the treat shoulder pain. Therefore, when examining the use of Tai Chi for upper limb rehabilitation post stroke, shoulder pain may be an important index to document.

2.7 Summary

In summary, the hemiplegic upper limb requires greater recovery to fulfill fine tasks compared with lower limb recovery. Furthermore, its natural motor recovery is slow and influenced dramatically by the severity of impairment level. Moreover, motor function of the involved upper limb is easily compensated by uninvolved upper limb thus resulting in secondary impairments. Rehabilitation for stroke patients in a chronic stage and with severe upper limb impairment are challenging. The effectiveness of upper limb rehabilitation approaches after stroke is suboptimal. These raise issues pertinent for novel and effective upper limb rehabilitation techniques.

Typified by slow and soft movements, Tai Chi is a popular, convenient and effective rehabilitation exercise suitable for persons in different situations. Tai Chi has been reported as beneficial for improving balance post stroke. However, its use for upper limb rehabilitation remains unknown. If Tai Chi is developed as a new technique for upper limb rehabilitation post stroke, two important factors may be needed to take into account. One is to make stroke patients capable of performing Tai Chi movements and increasing the number of movement repetitions during sessions or life activities; the other is to make the movement repetitions possible even in the case of severe motor impairment. However, the presence of hemiparesis, shoulder pain and severe spasticity of the affected arm may be barriers to use Tai Chi for upper limb rehabilitation, potentially limiting the ability to perform the Tai Chi movements. Therefore, Tai Chi needs to be adapted to be able to use for upper limb rehabilitation. Moreover, the acceptability of the adapted Tai Chi and its efficacy in improving upper limb function remain to be explored.

Chapter 3. Objectives of the study

The purpose of this study was to explore the use of adapted Tai Chi movement for upper limb rehabilitation post stroke. More specifically, the objectives were to evaluate the feasibility and effects of using adapted Tai Chi for upper limb rehabilitation in chronic stroke patients, including the following:

O1: The first objective was to evaluate the feasibility of offering an adapted Tai Chi exercise program for upper limb rehabilitation post stroke, including:

O1-a: To document the clinical reasoning underlying the adaptations made to Tai Chi based on the participants' characteristics when used for upper limb rehabilitation post stroke.

O1-b: To evaluate whether the adapted Tai Chi was doable and acceptable by participants in a chronic stage with different impairment level of upper limb and balance;

O1-c: To evaluate whether the potential influencing factors including impairment level of upper limb, insufficient balance, shoulder pain and spasticity constrained the practice of the adapted Tai Chi;

O2: The second objective was to evaluate the effects of the adapted Tai Chi exercise program on upper limb rehabilitation, including:

O2-a: To determine the efficacy of the adapted Tai Chi in improving motor function of the paretic upper limbs and activity of daily living of participants

O2-b: To determine the impact of upper limb impairments level on the adapted Tai Chi efficacy.

O3: The third objective was to evaluate participants' perception of the adapted Tai Chi, including:

O3-a: To determine their perceived usefulness of the adapted Tai Chi;

O3-b: To determine their perceived ease of practicing the adapted Tai Chi (i.e. the extent to which they felt they could easily do the adapted Tai Chi).

Chapter 4. Methods

4.1 Study design

A single group pretest-posttest design was used in this exploratory study. All participants underwent an 8-week Tai Chi intervention, with a pre and post evaluation and a 4-week follow-up evaluation. The research plan and time points of measurement are shown in Figure 1.

Figure 1. Research plan and the measurement time points.

4.2 Definition and selection of the study population

4.2.1 Target population

Stroke patients with paresis of upper limb were recruited in this study. The inclusion criteria were: 1) a history of stroke with paretic upper limb, at least 6 months before the start of the study; 2) upper limb recovery between stage 2 to 6 for Chedoke-McMaster Arm Impairment Inventory, or presence of upper limb dysfunction as reported by participants in stage 7; 3) able to understand the instructions to participate in assessments and Tai Chi interventions. The reason participants in stage 7 were included was because although stage 7 is defined as “normal,” stroke survivors in this stage may still have difficulties using their paretic upper limb, as reported by the participant. Moreover, to include patients in stage 2 to 7 enabled the sample of the study to have a wide range of disability level, which may facilitate the exploration of the feasibility of Tai Chi for upper limb rehabilitation post stroke.

The exclusion criteria were: 1) currently participating in a program for upper limb rehabilitation, 2) uncontrolled medical problems, 3) significant visual problems like hemianopia that would limit the ability to see the instructor, and 4) moderate or severe aphasia limiting their ability to participate in the study.

4.2.2 Sample

A convenience sample of 12 community-dwelling chronic stroke survivors was recruited in this study. The Tai Chi training and assessments were performed at a research site of Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR)-Institut de réadpatation Gingras-Lindsay de Montréal site in Montreal, Quebec, Canada. Patients were recruited from the rehabilitation center and stroke community and rehabilitation programs in Montreal. The coordinator of the study contacted patients by telephone and introduced the research. Participants who met eligibility criteria and were able to participate in Tai Chi sessions twice a week at the research site of CRIR were recruited.

4.2.3 Ethical considerations

The study protocol was approved by the CRIR's research ethics board (see Appendix A). The participants were informed about the course of the study during the first phone contact. The benefits and risks of the study were clearly explained to potential participants. Written informed consent was obtained from all participants before the first evaluation (see consent form in Appendix A). Also, participants were free to withdraw from the study at any time.

4.3 Intervention

Participants underwent a 60-minute Tai Chi session twice per week for 8 weeks. Sessions were delivered individually by Shujuan Pan (the master's degree candidate), a clinician with two years of Tai Chi experience. A 10-minute Tai Chi home program was also provided and recommended to be done on days without sessions and during the follow-up period (i.e. weeks 9-12). Each session included a 5-minute warm-up sequence, a 5-minute cool down sequence, and 50-minutes of adapted Tai Chi with rests if necessary.

The adapted Tai Chi consisted of eight forms selected from traditional styles. These were chosen for their simplicity and potential therapeutic effects for the upper limb. Two forms deriving from Chen style, known as Front Cloud Hands and Side Cloud Hands, emphasized shoulder abduction, flexion, and external rotation. Six forms chosen from Yang style had an emphasis on elbow extension, supination of forearm and dorsiflexion of wrist and fingers. From simple to complex sequence these are known as Brush Knees and Push, Parting Wild Horse's Mane, Fair Lady Works at Shuttles, Parry Block and Punch, Cloud Hands from Yang style, Step Back and Repulse Monkey. The forms from Chen style and the first two forms from Yang style were basic forms for all participants; other forms from Yang style were used depending on the participants' upper limb function

The Tai Chi training followed a gradual, part-to-whole, and easy-to-difficult progression. The instructor selected the appropriate adapted Tai Chi forms based on the participants' ability during the sessions. Muscle relaxation during movements was prioritized over precision of movements. Participants were encouraged to relax muscle and joints and focus on movements to help muscle relaxation. Movements were practiced slowly, repeatedly and even segmentally if necessary. Active movements were performed with the affected limb even if the range of motion was small, although assistance using the unaffected hand was allowed at the beginning.

4.4 Outcomes

4.4.1 Participant Characteristics

The demographic and clinical characteristics of all participants were collected, including age, gender, side of hemiparesis, type of stroke, time since stroke, comorbidities, co-rehabilitation, Botulinum toxin injection history and technical aids for mobility. The Severity Index of Cumulative Illness Rating Scale for Geriatrics (CIRS-G) was used to document their comorbidities with scores ranging from 0-4 (see Appendix B) (143). Since stroke was the primary diagnosis, it was excluded as a comorbidity. The initial arm and hand motor function stages were evaluated using the Chedoke-McMaster Stroke Assessments (CMSA), which has a range of stages from one to seven (36). The Modified Ashworth Scale (MAS), a 6-point scale ranging from 0-4, was used to grade initial spasticity level of paralytic upper limbs (144, 145).

4.4.2 Documentation of clinical reasoning for adapting Tai Chi

During the sessions, the instructor modified Tai Chi for participants based on initial upper limb function and balance levels of participants. Participants were asked to practice Tai Chi movements with both upper limbs. However, upper limb movements would be practiced one side at a time or both together according to the impairment level of the involved upper limb. Three lower limb positions were employed including sitting, fixed step and moving step positions based on balance level. The balance level was divided into two categories: sufficient or insufficient to support standing position to practice Tai Chi.

Two key principles were sequentially followed by the instructor when selecting the appropriate upper limb movements and lower positions for each participant: 1) the participant should be able to practice the Tai Chi movements while relaxing; 2) there should be as much whole-body coordination as possible. For example, participants who had insufficient balance to support standing position, would be assigned to use a sitting position. All decision made by the instructor regarding the choice of upper limb movements (one side at a time or both arms together) and lower positions during adaptation process were documented in a log. Also, how participants executed Tai Chi movements using their affected arm was documented, including the forms that they were capable of practicing, smoothness of the practice, and whether they need assistance from the non-affected hand to fulfill the movements.

4.4.3 Adherence to Tai Chi sessions and self-practice at home

Session attendance and reasons for dropouts were recorded. Number of times and duration of self-practice at home were recorded by participants in a log book and collected by the instructor at each session and the end of follow-up period. Number of falls during Tai Chi sessions and self-practice at home were also recorded.

4.4.4 Outcome measures

Three primary outcome measures were collected at three time points: baseline, post-treatment and follow-up (see Appendix C). Motor function of upper limb were measured with the Fugl-Meyer Assessment upper-limb section (FMA-UL)(146) and the Wolf Motor Function Test (WMFT)(147). Items of the FMA-UL are scored on a 3-point ordinal scale, ranging from 0 to 2 and have a maximum score of 66. Previous research studies examining the FMA have established that it has good construct, criterion validity and reliability (35, 148, 149).

WMFT is an impairment-based test which is composed of functional ability, time and strength parts. It includes 15 function and time-based tasks using a 6-point functional ability scale to rate the quality of movement while recording performance time simultaneously. There are also two strength-based tasks (lifting the weighted limb and grip strength). The maximum time permitted to complete an item of WMFT is 120 seconds. Tasks which cannot be completed within 120 seconds are noted as 121 seconds, and the number of such tasks was used as an outcome variable. Among chronic stroke survivors, construct, convergent, and discriminate validity and good reliability of WMFT have been reported (147, 150, 151).

Activities of daily living (ADL) were measured with the Modified Motor Activity Log (MAL). This assessment consists of a total of 14 specific ADL motions using a 6-point ordinal scale to rate the use of their paretic arm and hand (the amount of use, AOU) and quality of movement (QOM) (152). Good criterion validity and reliability of the MAL have been reported (152, 153). Shoulder pain of affected arms at the three time points was used as a secondary outcome measure using the Visual Analogue Scale (VAS) with scores ranging from 0-10 (154). The evaluations were performed by two evaluators who were not involved in other aspects of the study.

4.4.5 Participants' perception of Tai Chi

At the follow-up evaluation, a feedback questionnaire (see Appendix C), modified from the short feedback questionnaire evaluating virtual reality experience (155), was used to assess participants' perception of the use of Tai Chi. Perceived usefulness and ease of practicing of Tai Chi from participants, as two important aspects to assess a novel intervention, were documented. The questionnaire included 18 questions, 10 using a five-point ordinal scale, 3 using a seven-point ordinal scale, and the remaining issues were open-ended questions.

4.5 Data analysis

Descriptive statistics were used to analyze all variables. Frequencies were calculated to check extreme values. To compare self-practice for participants with different levels of upper limb function, shoulder pain and spasticity, participants were divided into three types of subgroups:

low (arm stage 2 of CMSA), middle (arm stage 3 to 5) and high (arm stage 6 and better) upper limb function groups; shoulder pain group (VAS>0) and no shoulder pain group (VAS=0); moderate to severe spasticity group (MAS ≥ 2), and slight or no spasticity group (MAS<2).

Since the WMFT performance time presented a skewed distribution, a logarithmic transformation was performed to meet assumptions of normality. For better interpretation, logs values were converted back to seconds. To evaluate the treatment's effect on outcome variables, linear mixed models for repeated measures were performed with time as the within-subject factor. In other words, the treatment by time interaction was the main assessment of the intervention. The best variance-covariance structure in mixed models was selected to fit different data of variables. Changes from baseline to post-treatment and baseline to follow-up were also analyzed by mixed models. Moreover, based on the functional level of paretic upper limb, participants were divided into subgroups to compare the differences of subgroups effects visually, though statistical tests could not be performed given the sample size of subgroups.

All statistical analyses were conducted using the SPSS statistical program ver. 23.0, and significance was accepted at values of $p<0.05$.

Chapter 5. Results

The results from this study are presented in the following results section in two scientific articles. The first article focuses on the feasibility and acceptability of offering an adapted Tai Chi exercise program for upper limb rehabilitation post stroke. A clinical reasoning algorithm underlying the adaptation of Tai Chi is also presented. The second article focuses on the effects of the adapted Tai Chi used for upper limb rehabilitation post stroke, and participants' perception of the adapted Tai Chi, including their perceived usefulness of the adapted Tai Chi and perceived ease of practicing the adapted Tai Chi.

5.1 Article 1

Title: Adapting Tai Chi for upper limb rehabilitation post stroke: a feasibility study

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As the main author, Shujuan Pan participated in the design of the study, the development of the intervention, the choice of outcome measures, recruiting, collecting, analyzing and interpreting data as well as the writing of the manuscript. Dr. Dahlia Kairy (director) oversaw the entire experimental process including study design, the choice of outcome measures, analysis and interpretation of data, and revision of the manuscript. Dr. Michel Tousignant (co-director) and Dr. Hélène Corriveau participated in study design, data interpretation, and revision of the manuscript.

Abstract

Background: Tai Chi (TC) has been reported as beneficial for improving balance post stroke, yet its use for upper limb (UL) rehabilitation remains unknown.

Objective: To explore the feasibility of TC on UL rehabilitation post stroke

Methods: Twelve chronic stroke survivors with a persistent paretic UL underwent 60-minute adapted TC sessions twice a week for eight weeks and a 4-week follow-up evaluation. A 10-minute TC home program was recommended for the days without sessions. TC level of performance, attendance to the sessions, duration of self-practice at home, adapted TC movements used were recorded. Shoulder pain was measured by Visual Analogue Scale (VAS).

Results: Eleven participants completed the study. A clinical reasoning algorithm underlying the adaptation of TC elaborated throughout the trial. It was developed based on different functional levels of the participants. Participants with different profiles including severely impaired UL, poor balance, shoulder pain, and severe spasticity were not only capable of practicing the adapted TC but attended all 16 sessions and practiced TC at home a total of 16.51±9.21 hours. The self-practice amount for subgroups with lower UL function, shoulder pain or moderate-to-severe spasticity, was similar to subgroups with higher functional UL, no shoulder pain, and minimal-to-no spasticity. Shoulder pain of four participants decreased following TC (VAS 5.5±3, 3±2.8, 2.5±2.5 for the pre, post and follow-up period respectively).

Conclusions: Adapted TC is feasible for UL rehabilitation post stroke. Low UL function, insufficient balance, spasticity, and shoulder pain do not seem to hinder practicing TC. Further evaluation of its efficacy is required.

Keywords: Stroke; Rehabilitation; Upper extremity; Tai Ji; Feasibility

Introduction

Stroke is a leading cause of serious, long-term disability among middle-aged and older adults worldwide (1). Functional impairment of the upper limb is reported in approximately 85% of stroke survivors (2), which is one of the most significant challenges for stroke rehabilitation. At six months post stroke, 30-60% of individuals do not regain functional use and only 5-20% will achieve full recovery of arm function (3). Though upper limb recovery has been reported to improve even in chronic stroke stages (4), the effects of current treatments for arm weakness are shown to be modest (5). Moreover, long-term rehabilitation services are limited to a large proportion of chronic stroke patients after returning home (6, 7). Therefore, novel and effective approaches are needed to provide timely and ongoing upper limb rehabilitation.

Tai Chi is an ancient martial art originating from Chinese healing traditions. Typified by slow and soft movements, it is widely accepted as a suitable, low impact, home-based exercise option for the aged and patients with chronic diseases (8-10). Through slow and continuous weight transfer between two feet, Tai Chi has been proven effective in improving balance and for fall prevention in older adults (11-13). In recent years, there is some evidence supporting its benefits in improving balance in chronic stroke patients (14-16). However, no study had reported the use of Tai Chi for upper limb rehabilitation post stroke. Considering that Tai Chi is a whole-body exercise, muscle strength, and flexibility of upper limb have been shown to improve in the aged following Tai Chi (17-19). Furthermore, since muscular relaxation training has been suggested as a means to control involuntary muscular activity (20), the relaxation component of Tai Chi may have the potential to improve spasticity of the paretic upper limb. Therefore, Tai Chi may be a promising treatment for upper limb rehabilitation post stroke.

However, the presence of hemiparesis may potentially limit the ability of stroke survivors to perform the Tai Chi upper limb movements. Similarly, shoulder pain and severe spasticity of the affected arm may impact on the capacity to perform Tai Chi movements. Furthermore, the standing position used in traditional Tai Chi styles poses difficulties for persons with poor balance. Adapting Tai Chi to take into account these limitations may need to be included in post-stroke rehabilitation. Therefore, this study aimed to explore the feasibility of using adapted Tai Chi for upper limb rehabilitation post stroke, including (1) whether the adapted Tai Chi was doable and acceptable by participants and (2) whether the potential influencing factors such as impairment level of upper limb, insufficient balance, shoulder pain and spasticity constrained the practice of the adapted Tai Chi. A second objective was to document the clinical reasoning underlying the adaptations made to Tai Chi based on the participants' characteristics when used for upper limb rehabilitation post stroke.

Methods

Study design

A single group pretest-posttest design was used in this exploratory study. All participants underwent an 8-week Tai Chi intervention and a 4-week follow-up evaluation.

Sample

12 community-dwelling chronic stroke survivors were recruited in this study. The inclusion criteria were: 1) history of stroke with paretic upper limb, at least 6 months before the start of the study; 2) upper limb recovery between stage 2 to 6 for Chedoke-McMaster Arm Impairment Inventory (21), or presence of upper limb dysfunction as reported by participants in stage 7; 3) able to understand the instructions to participate in assessments and Tai Chi interventions. The exclusion criteria were: 1) currently participating in a program for upper limb rehabilitation, 2) uncontrolled medical problems, 3) significant visual problems like hemianopia that would limit the ability to see the instructor, and 4) moderate or severe aphasia limiting their ability to participate in the study. The study protocol was approved by the Ethics Committee of Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR). Written informed consent was obtained from all participants before the pre-treatment.

Intervention

Participants underwent a 60-minute Tai Chi session twice per week for eight weeks. Sessions were delivered individually by Shujuan Pan, a clinician with two years of Tai Chi experience in a research center that is part of the CRIR. A 10-minute Tai Chi home program was proposed to be done on days without sessions and during the follow-up period (i.e. weeks 9-12). Each session included a 5-minute warm-up sequence, a 5-minute cool down sequence, and 50-minutes of adapted Tai Chi.

The Tai Chi intervention consisted of eight forms selected from traditional styles. Two forms deriving from Chen style, known as Front Cloud Hands and Side Cloud Hands, emphasized shoulder abduction, flexion, and external rotation. Six forms chosen from Yang style had an emphasis on elbow extension, supination of forearm and dorsiflexion of wrist and fingers. From simple to complex sequence these are known as Brush Knees and Push, Parting Wild Horse's Mane, Fair Lady Works at Shuttles, Parry Block and Punch, Cloud Hands from Yang style, Step Back and Repulse Monkey. The forms from Chen style and the first two forms from Yang style were basic forms for all participants; other forms from Yang style were used depending on the participants' upper limb function.

The Tai Chi training followed a gradual, part-to-whole, and easy-to-difficult progression. The instructor selected the appropriate adapted Tai Chi forms based on the participants' ability during the sessions. Muscular relaxation was particularly emphasized during practice. Movements were practiced slowly, repeatedly and even segmentally if necessary. For participants with low upper limb function, only shoulder and elbow movements were emphasized. Active movements were performed with the affected limb even if the range of motion was small, although assistance using the unaffected hand was allowed at the beginning.

Outcomes

Participant characteristics. The demographic and clinical characteristics of all participants were collected, including age, gender, side of hemiparesis, type of stroke, time since stroke, comorbidities, co-rehabilitation, Botulinum toxin injection history and technical aids for mobility. The Severity Index of Cumulative Illness Rating Scale for Geriatrics was used to document their comorbidities with scores ranging from 0-4 (22). The initial arm and hand motor function stages were evaluated using the Chedoke-McMaster Stroke Assessments (CMSA) (21), which has a range of stages from one to seven. The Modified Ashworth Scale (MAS) (23, 24), a 6-point scale ranging from 0-4, was used to grade spasticity level of paralytic upper limbs.

Adherence to Tai Chi sessions and self-practice at home. Session attendance and reasons for dropouts were recorded. Number of times and duration of self-practice at home were recorded by participants in a log book and collected by the instructor at each session and the end of follow-up period.

Documentation of clinical reasoning for adapting Tai Chi. During the sessions, the instructor modified Tai Chi for participants based on initial upper limb function and balance levels of participants. Participants were asked to practice Tai Chi upper limb movements one side at a time or both together, according to the impairment level of the involved upper limb. Three lower limb positions were employed including sitting, fixed step and moving step positions based on balance level. The balance level was divided into two categories: sufficient or insufficient to support standing position to practice Tai Chi.

Two key principles were sequentially followed by the instructor when selecting the appropriate upper limb movements and lower positions for each participant: 1) the participant should be able to practice the Tai Chi movements while relaxing; 2) there should be as much whole-body coordination as possible. All decision made by the instructor regarding the choice of upper limb movements (one side at a time or both arms together) and lower positions during adaptation process were documented in a log. Also, how participants executed Tai Chi movements using the affected arm was documented, including the forms that they were capable of practicing, smoothness of the practice, and whether they need assistance from the non-affected hand to fulfill the movements.

Shoulder pain and falls. The Visual Analogue Scale (VAS) (25) with scores ranging from 0-10 was used to measured shoulder pain of affected arm at baseline, post-treatment, and 4-week follow-up. Good concurrent validity, test-retest reliability and sensitivity to change of VAS have been reported (26-28). Number of falls during Tai Chi sessions and self-practice at home were also recorded.

Data analysis

Descriptive statistics were used to analyze all variables. Frequencies were calculated to check extreme values. To compare self-practice for participants with different levels of upper limb function, shoulder pain and spasticity, participants were divided into three types of subgroups: low (stage 2 of CMSA-arm), middle (stage 3 to 5) and high (stage 6 and better) upper limb function groups; shoulder pain group (VAS>0) and no shoulder pain group (VAS=0); moderate to severe spasticity group (MAS⩾2), and slight or no spasticity group (MAS<2). Analyses were conducted using the SPSS statistical program ver. 23.0.

Results

Clinical characteristics

Twelve chronic stroke survivors participated the study. One withdrew after having participated in three sessions because of lack of public adapted transport services. For the purposes of the study, the analysis was conducted on the 11 remaining participants. The clinical characteristics of participants are presented in Table 1. They were on average 59.4±13.0 years old and 22.7±17.7 months after stroke onset. Two out of eleven were women, and four had dominant-side hemiparesis. Unexpectedly, three participants were found to participate in other community exercise programs for 20-30 minutes per week. Given that the time spent was much less than that of the Tai Chi, they were not excluded in the study. Comorbidities included hypertension (n=5), diabetes mellitus (n=2), heart bypass surgery (n=1), kidney and pancreas transplantation (n=1), bilateral total knee replacement (n=1), and extreme obesity (n=1).

Adherence to Tai Chi sessions and self-practice at home

The eleven participants participated in all 16 sessions of Tai Chi within two months. After the first session, they were able to begin practicing the adapted Tai Chi at home. In the first month, six participants practiced Tai Chi at home on more than 17 days; four practiced on 9 to 17 days; one subject practiced on 2 days (a total of 0.3 hours). However, for this same participant, his self-practice increased to 20 days (4.2 hours) and 25 days (6.3 hours) in the second and the third month respectively. In the second and third month, eight participants practiced more than 17 days; two practiced 9 to17 days, and one practiced less than 8 days. They practiced Tai Chi at home with a range of 5-45 minutes per day. Their individual self-practice hours per month are presented in Figure 1.

The mean self-practice time of participants in the first month was 3.5±1.8 hours, and this increased significantly in the second and third month by 6.0±3.7 and 6.97±4.7 hours respectively (Figure 2). Only two participants (subject No. 4 and 9) decreased their practice at the follow-up by 3 days (0.8 hours) and 9 days (1.1 hours). Both participants reported it was hard to get self-practice into a routine without the motivation of actual in-person sessions.

Table 1. Demographic and clinical characteristics of participants.

Subject	Age	Gender	Side of hemiparesis	Dominant-side hemiparesis	Stroke type	Time after onset (months)	CIRS-G Severity Index (max 4)	Co-treatment	Technical aids for mobility	Initial CMSA (arm)	Initial CMSA (hand)	Spasticity (MAS) (max 4)	BTX injection	Initial Shoulder pain (VAS) (max 10)
1	41	M	L	No	Hem	50	3.0	No	Cane	2	2	4	Yes	3
2	62	M	L	No	Isc	24	0	No	Cane	2	2	3	Yes	3
3	53	M	R	Yes	Isc	14	0	Yes	Cane	2	2	3	Yes	0
4	54	M	R	Yes	Isc	10	0	Yes	Independent	3	2	2	No	0
5	46	M	L	No	Hem	13	3.3	No	Cane	3	4	1	No	0
6	65	F	R	Yes	Isc	56	2.0	No	Independent	3	2	0	No	0
7	87	M	R	Yes	Isc	10	4.0	Yes	Wheelchair	3	5	1	No	9
8	63	M	L	No	Hem	41	0	No	Independent	3	4	2	No	0
9	47	M	L	No	Isc	8	3.0	No	Independent	6	6	0	No	7
10	67	M	L	No	Isc	12	2.5	No	Independent	6	6	0	No	0
11	68	F	R	No	Isc	12	3.0	No	Independent	7	7	0	No	0

Abbreviations: F=female; M=male; R=right; L=left; Hem=hemorrhagic stroke; Isc=ischemic stroke; CIRS-G, Cumulative Illness Rating Scale for Geriatrics; CMSA, Chedoke-McMaster Stroke Assessments; MAS, Modified Ashworth Scale; BTX, Botulinum toxin; VAS, Visual Analogue Scale.

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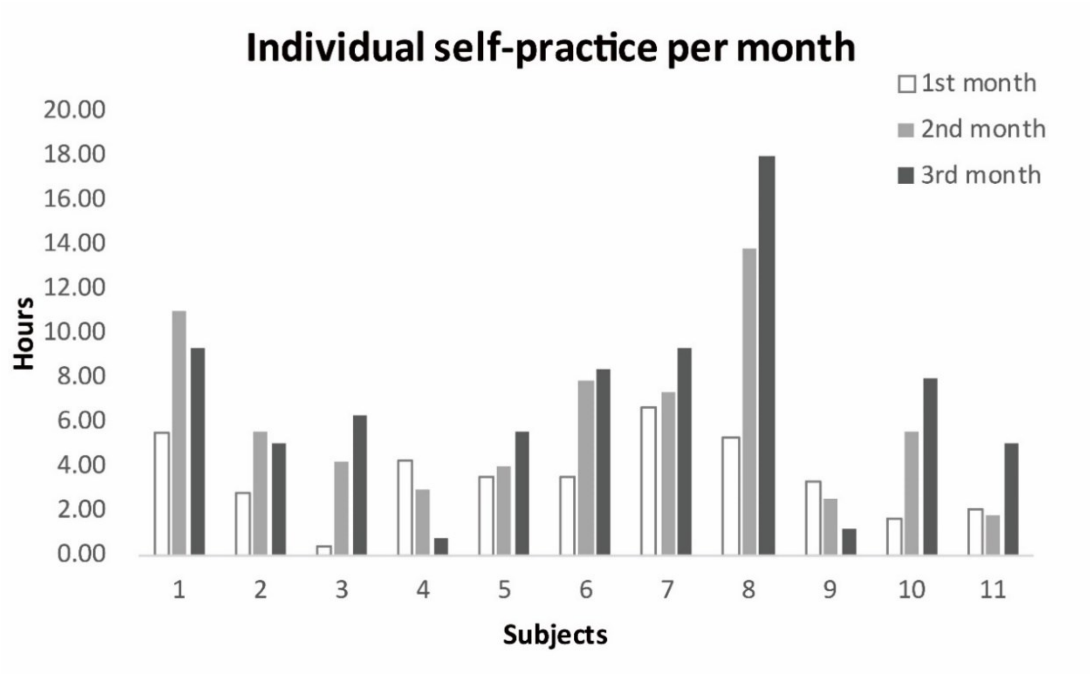

Figure 1. Individual self-practice hours per month.

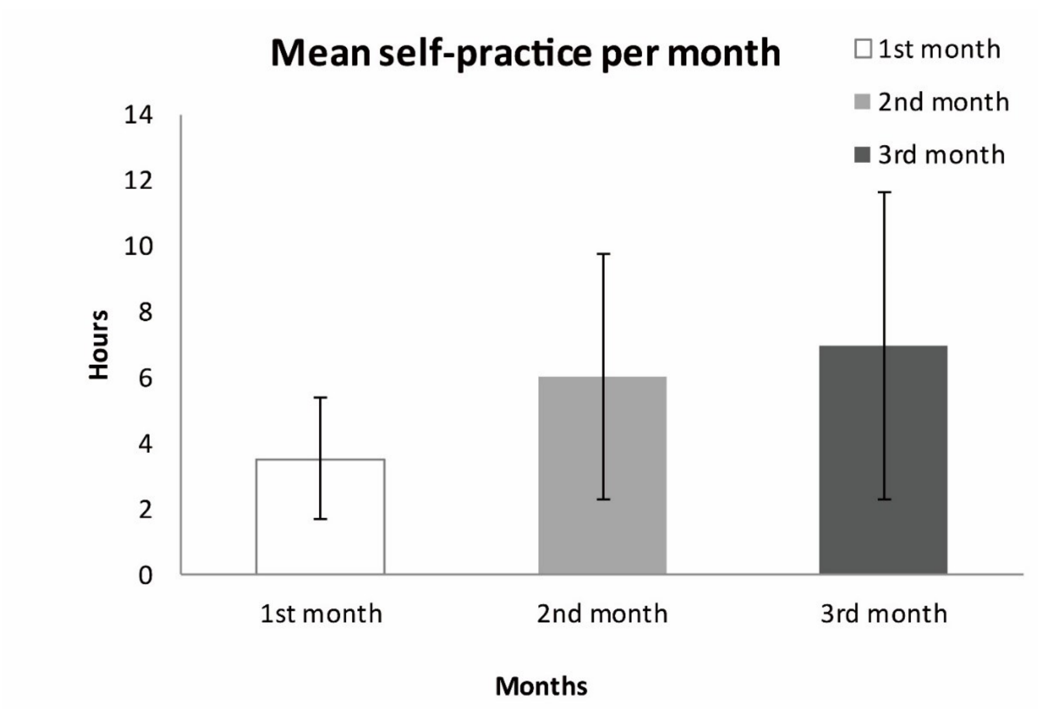

Figure 2. Mean participant self-practice hours per month. Note: There were 22 days for self-practice in the first and second month, 28 days in the third month (follow-up period with no active intervention).

Clinical reasoning underlying Tai Chi adaptations

The clinical reasoning process for adapting Tai Chi during sessions is presented in Figure 3. Participants were asked to practice Tai Chi with both upper limbs whose movements were different. According to the impairment arm stage of CMSA, participants in stage 2 practiced upper limb movements one side at a time. Participants in stage 3 practiced upper limb movements one side at a time at first and then changed gradually to both sides after they were familiar with the movements and improved their practice ability. Participants in stage 6 and better directly practiced both sides together.

Three lower limb positions were employed based on balance level, including sitting, fixed step and moving step positions. Sitting position was used in participants whose balance was insufficient to support standing. Fixed step and moving step positions were two standing positions used for persons with sufficient balance to support standing. They refer to standing with weight shifting between two feet, with (moving step position) or without actually stepping (fixed step position). Taking upper limb ability into consideration, moving step position required both high upper limb function and sufficient balance, while fixed step position could be used in persons with low upper limb function. These three positions were combined by a part-to-whole and easy-to-difficult way to make participants gradually increase their practice ability. Therefore, participants who had sufficient balance to support standing used sitting and fixed step positions when upper limb function was in stage 2 or 3 and used fixed step and moving step positions when upper limb function was in stage 6 or 7. Each position took up half a session.

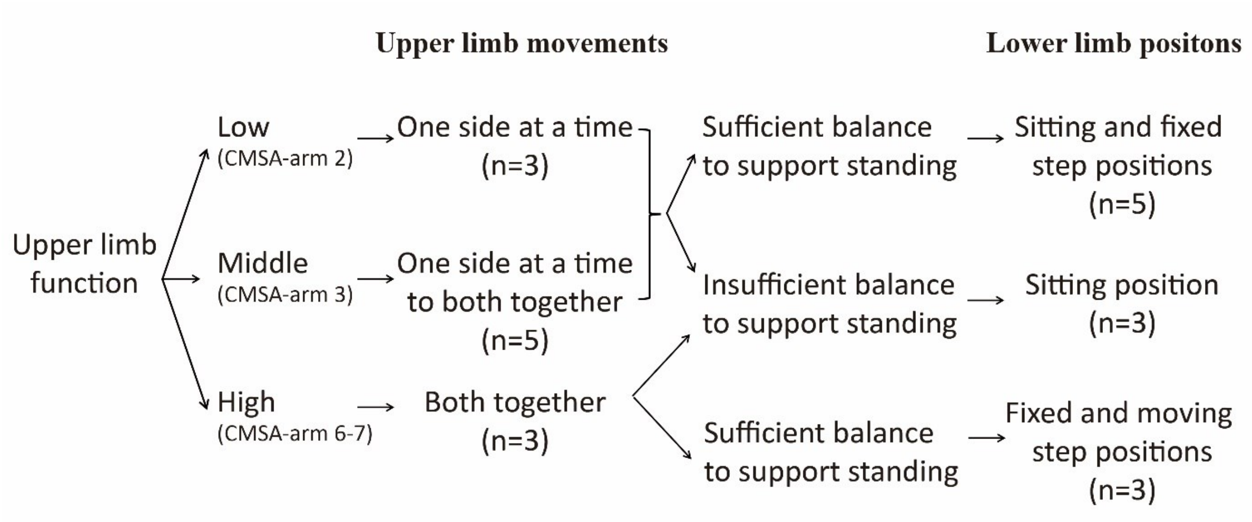

Figure 3. Clinical reasoning for adapting Tai Chi in the study, including upper limb movements and lower limb positions used by participants. Abbreviations: CMSA-arm, arm stage of Chedoke-McMaster Stroke Assessments.

Tai Chi performance and adaptations in different situations

Upper limb impairment level. According to initial arm stage using CMSA, three participants were in stage 2, five in stage 3, and three in stage 6 and better (Table 1). Participants in stage 2 had isolated shoulder movements without incorporating the trunk movements before starting the study. They were capable of practicing upper limb movements one side at a time, though motion ranges of affected arms were small when doing movements independently. As well, they required assistance from the non-affected hand to complete the active movements of the affected limb at the beginning. Five participants in stage 3 practiced upper limb movements one side at a time first and then changed gradually to both sides once their abilities are permitted. Four of them changed to practice both sides together at the end of 16 sessions. Their affected arms could finish movements independently. Participants in stage 6 and better practiced upper limb movements with both sides without modification. The subgroups' self-practice hours per month are presented in Figure 4. The total self-practice time in three months (intervention plus follow-up) of the high upper limb functional group (stage 6 and better) were less than those of low (stage 2) and middle (stage 3) upper limb functional group (10.3±4.3hours, 16.6±18.1 hours, and 20.2±11.1 hours respectively).

Insufficient balance and falls. Regarding initial mobility aids used, one participant used a wheelchair, four used a cane, and six were independent (Table 1). The participant who used a wheelchair and two participants who used a cane had insufficient balance to support standing and thus practiced Tai Chi in a sitting position. Three independent participants who were in stage 6 and better practiced in fixed and moving step positions. Five participants including two using a cane and three independent ones, had sufficient balance while their arms were in CMSA stage 2 or 3, practiced in sitting and fixed step positions. No fall was recorded throughout the study.

Shoulder pain. Four participants had initial shoulder pain in the affected upper limb with a mean VAS of 5.5±3, and two of them present a CMSA-arm score over 7 (Table 1). The shoulder pain appeared during movement but did not interfere with Tai Chi movements. Moreover, their shoulder pain decreased to a mean VAS 3±2.8 after intervention and 2.5±2.5 at the end of follow-up. Participants without initial shoulder pain did not feel any shoulder pain during the whole study. The total self-practice over the three months was similar in the shoulder pain group (VAS>0) and no shoulder pain group (VAS=0) (17.8±7.7 hours and 15.4±10.9 hours respectively; Figure 4).

Spasticity. The initial spasticity level of participants is shown in Table 1, with the mean MAS 1.5±1.4. Three participants had severe spasticity (MAS ≥3) and required more time to relax before starting a movement as well as a pause during movement. All three participants received Botulinum toxin injections regularly before participating in the Tai Chi intervention to reduce spasticity. They did not receive any injections during the study time when reinjection time came. The total self-practice time over the three months for the moderate-to-severe spasticity group (MAS ≥ 2) was 18.9±12.2 hours, while it was 14.5±6.3 hours in the slight or no spasticity group (MAS < 2; Figure 4).

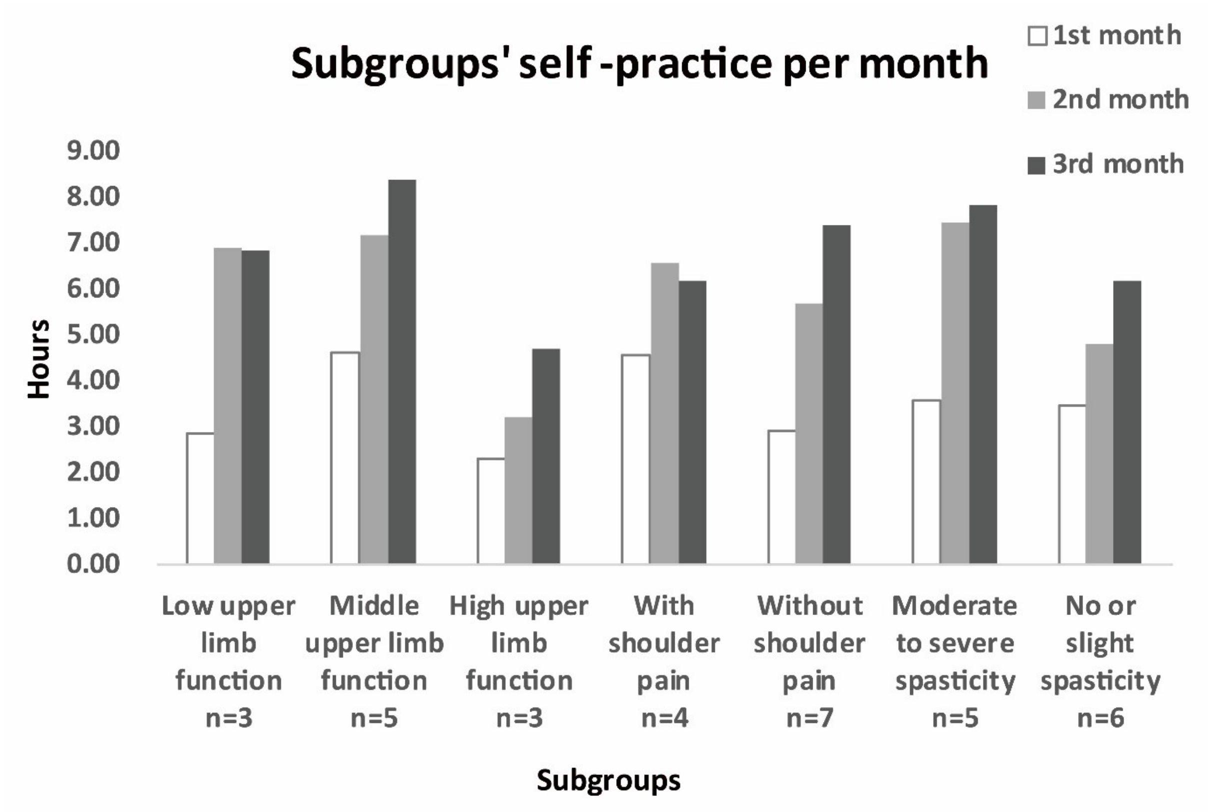

Figure 4. Subgroups' self-practice hours per month of participants.

Discussion

The objective of this study was to explore the feasibility of Tai Chi on upper limb rehabilitation post-stoke and its influencing factors. The underlying clinical reasoning was identified in the study to tailor the Tai Chi training to different functional levels of the participants. The results show that participants with various characteristics including severely impaired upper limb, poor balance, shoulder pain, severe spasticity, high medical comorbidity burden, and the elderly were capable of practicing their selected adapted Tai Chi movements. Moreover, the adapted Tai Chi was well accepted by participants. Participants not only attended all Tai Chi sessions but also practiced Tai Chi more than expected at home even in the follow-up month. The total self-practice hours of subgroups with low upper limb function (stage 2 or 3), shoulder pain (VAS>0) and moderate and severe spasticity (MAS⩾2) were not less than those of their corresponding subgroups, though in this exploratory study sample sizes of subgroups were too small to perform inferential statistical analysis. Initial shoulder pain of four participants decreased after the intervention. This study, therefore, suggests that Tai Chi was feasible for upper limb rehabilitation post stroke after having been adapted for the hemiparesis of stroke survivors. Impairment level of the affected upper limb, impaired balance, shoulder pain and spasticity are not limiting factors for practicing adapted Tai Chi post stroke. To our knowledge, this is the first study to report the feasibility of Tai Chi on upper limb rehabilitation after stroke.

It was recommended to participants that they practice 10 minutes of Tai Chi at home on those days without sessions. Such self-administered exercise programs by patients during their off-therapy time have been recommended and proven effective in improving arm-hand function (29). Unlike many Tai Chi programs, the adapted Tai Chi in the study was simple and easy to learn so that participants were able to practice it at home after the first session. In the first month, their practice at home was in line with expectations. In the second and follow-up months, most participants increased their self-practice time, to an extent far more than expected. The reasons may be that they were more familiar with the movements after the first month, or maybe they felt some improvements and thus more motivated to practice by themselves even in the follow-up. Altogether, aside from the 16 sessions, participants practiced at home a total of 16.5±9.2 hours over the three months. The adapted Tai Chi was highly appreciated by participants.

Two principles were used to adapt Tai Chi in this study. The first one was to adapt movements of involved upper and lower limbs to make participants able to practice Tai Chi. For severely impaired upper limbs, several strategies were used to facilitate practicing. First, Tai Chi movements were modified from both sides together to one side at a time. Second, practice requirements for affected sides were to move mainly shoulder and elbow while not for hand movements. Movements were proposed to practice slowly and even segmentally. Moreover, active movements of the affected sides were assisted by the unaffected hands. Consequently, participants in stage 2 and 3 were able to practice their selected upper limb movements, and they practiced Tai Chi at home with good compliance, in fact even more than participants in stage 6 and better (Figure 4). Considering that movement practice is dramatically influenced by the level of impairment of the upper limb as reported by previous studies (30,31), the capability of participants in stage 2 and 3 to perform multiple repetitions of Tai Chi movements is already a meaningful advancement, although the efficacy of Tai Chi in this population remains to be confirmed in future studies. It should be noted that participants in stage 2 in the study were able to have isolated shoulder movements without compensatory the trunk movements before treatment. However, the feasibility of doing Tai Chi even when adapted with individuals who do not have isolated shoulder movements remains to be tested.

Regarding the paretic lower limbs, sitting position was used to replace traditional moving step position for patients without sufficient balance to support standing. One subject who used a wheelchair and two participants who used a cane practiced Tai Chi in a sitting position in the study. Although sitting Tai Chi has been reported to be used in persons with spinal cord injuries to improve muscle strength of upper limb (32), to our knowledge it is the first time it has been reported in stroke rehabilitation. No falls were recorded during the whole study. Thus this exploratory study suggests that Tai Chi can be safe when appropriately adapted to the participants' abilities. Furthermore, sitting position may also help persons with poor upper limb function to better concentrate on upper limb practice. It was also used in the study for those who had sufficient balance but poor upper limb function (stage 2 and 3). However, it should be noted that this study assessed balance level as being able or not to maintain the standing position during the intervention. Future studies should pursue the clinical reasoning to include more detailed balance evaluation data.

Another principle used when adapting the Tai Chi was to aim for whole body coordination as much as possible, which is an important feature of Tai Chi. Using the principle of coordination can also increase the practice difficulty and challenge participants to improve their ability, which is an important strategy in stroke rehabilitation. Firstly, both upper limbs were required to move together when upper limb function permitted. Different from bilateral arm training whereby patients practice the same activities with both upper limbs simultaneously (33), Tai Chi movements of both upper limbs were different which is more challenging (i.e. the arm movements performed by each side were different). From stage 3, participants were encouraged to practice upper limb movements together gradually. Results indicate that four of the five participants progressed to practicing both arms together at the end of 16 sessions, and participants in stage 6 and better could practice both arms from the start. Although there were no participants in stage 4 and 5, we tentatively put forward that they may also practice upper limb movements from one side at a time to both together as participants in stage 3, although this remains to be confirmed in future studies. Previous studies have reported that practicing bilateral movements improved the recovery of affected upper limb (34), the activation of the intact hemisphere may facilitate the recovery of the injured hemisphere through neural networks (35). Based on original Tai Chi forms, the bilateral movements in the study were different, which may have a different effect on functional recovery. Further research examining its effects is required.

Secondly, fixed and moving step positions were used to make upper and lower limbs coordinate under the condition of sufficient balance. To take into account the feasibility of upper limb and coordination with lower limb, a combination of lower limb positions was applied. Sitting and fixed step positions were chosen for participants with enough balance but low upper limb function, fixed and moving step positions were used for participants with enough balance and high upper limb function. The combinations also took challenge and ease of exercise into consideration. Since this clinical reasoning included lower limb exercise, it may be used not only for upper limb rehabilitation but also for rehabilitation of both upper and lower limbs in the future.

The feasibility of using Tai Chi for upper limb rehabilitation, not only be due to the adaptation of Tai Chi but may also be due to muscle relaxation practice, which was particularly emphasized during Tai Chi practice in the study. Muscle relaxation is the essential feature which differentiates Tai Chi from many other exercises (36). Without the need to support body weight, upper limbs are thought to be easier to relax than lower limbs during Tai Chi practice (37). Results showed that three participants with severe spasticity (MAS≥3), were able to follow Tai Chi sessions given more time for relaxation. They did not receive Botulinum toxin reinjections during the study. The total self-practice hours of participants in the subgroup with MAS≥2 was not less than those in the subgroup with MAS<2. These effects may be a consequence of the relaxation approach used. It should be noted that this study only assessed spasticity level before intervention as one of the participants' characteristics, to explore whether spasticity was an influencing factor which would constrain the Tai Chi practice. Interestingly, the findings of the present study showed that muscle relaxation practice may reduce spasticity and promote Tai Chi practicing. Future studies are needed which include spasticity as an outcome measure after the intervention, to provide more scientific evidence of the relaxation effects of Tai Chi.

Study limitations

The main limitation of this feasibility study is that this was a convenience sample with a small sample size. There were no participants in stages 4 and 5 to be able to make a complete portrait of the clinical reasoning for adapting Tai Chi, and we did not provide a detailed balance guideline for choosing lower limb positions. Future studies with a larger sample size may take more situations into accounts such as coordination and learning ability, to provide a complete clinical reasoning picture. Also, the sample size of subgroups was too small to perform inferential statistical analyses. In addition, the data for self-practice at home were the patient-reported outcomes which may not adequately reflect actual practice time.

Conclusion

Adapted Tai Chi is feasible for upper limb rehabilitation post stroke. A clinical reasoning algorithm for adapting Tai Chi based on relaxation and coordination principles can provide recommendations for clinicians and researchers. Our data suggest that chronic stroke survivors were able to and accepted practicing the adapted Tai Chi, despite different upper limb impairment levels. Tai Chi may be a promising upper limb rehabilitation strategy given that in this study participants pursued high amounts of self-practice at home. Low upper limb function, insufficient balance, spasticity, and shoulder pain do not appear to hinder Tai Chi practice. Future research is needed to provide a complete portrait of the clinical reasoning for adapting Tai Chi.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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5.2 Article 2

Title: Adapted tai chi enhances upper limb motor control in chronic stroke patients: a pilot study

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As the main author, Shujuan Pan participated in the design of the study, the development of the intervention, the choice of outcome measures, recruiting, collecting, analyzing and interpreting data as well as the writing of the manuscript. Dr. Dahlia Kairy (director) oversaw the entire experimental process including study design, the choice of outcome measures, analysis and interpretation of data, and revision of the manuscript. Dr. Michel Tousignant (co-director) and Dr. Hélène Corriveau participated in study design, data interpretation, and revision of the manuscript.

Abstract

Background: Tai Chi (TC) has been reported as beneficial for improving balance post stroke, yet no study examined the use of TC for upper limb rehabilitation.

Objective: To evaluate the efficacy and acceptability of TC for upper limb rehabilitation post stroke.

Methods: Twelve chronic stroke survivors with a persistent paretic upper limb underwent 60-minute adapted TC sessions twice a week for eight weeks and a 4-week follow-up. A 10-minute TC home program was recommended for the days without sessions. Motor function of the paretic arm ((Fugl-Meyer Assessment upper-limb section (FMA-UL), Wolf Motor Function Test (WMFT)) and paretic arm use in daily life (Motor Activity Log (MAL)) were measured at baseline, post-treatment and follow-up. A feedback questionnaire was used to evaluate participants' perception of the use of TC at follow-up.

Results: Eleven participants completed the 8-week study. Participants with varying profiles including severely impaired upper limb, poor balance, shoulder pain, and severe spasticity, were able to practice an adapted version of TC, they attended all 16 sessions and practiced TC at home more than recommended (a total of 16.51±9.21 hours). Participants demonstrated significant improvement over time in the FMA-UL ($p=.009$), WOLF functional scale ($p=.003$), WMFT performance time ($p=.048$) and MAL Amount of Use scale ($p=.02$). Moreover, participants confirmed the usefulness and ease of practicing the adapted TC.

Conclusion: TC was acceptable and found to be effective for upper limb rehabilitation post stroke after adaptation of movements. Further large-scale randomized trials evaluating TC for upper limb rehabilitation are warranted.

Keywords: Stroke; Rehabilitation; Tai Chi; Upper extremity

Introduction

Functional impairment of the upper limb (UL) is reported in approximately 85% of stroke survivors (1). Although recent approaches involving repetitive training of the paretic UL using task-oriented activities provide evidence of efficacy for improving UL function (2, 3), the effects of current treatments for arm weakness are shown to be modest (4). About 55% to 75% of stroke survivors have significant permanent UL deficits that hinder the quality of life (5). Novel and effective treatments are therefore required.

Tai Chi is an ancient martial art originating from China. Typified with slow and soft movements, Tai Chi is widely accepted as a suitable, low impact, home-based exercise option for the aged and patients with chronic diseases (6-8). Through consistent weight shifting between two feet (9), Tai Chi has been broadly reported beneficial for improving balance and for fall prevention in the elderly (10-12). Recently, there is some evidence supporting its benefits in improving balance in chronic stroke patients (13-15). However, its use for UL rehabilitation remains unknown.

Given that Tai Chi is not only an exercise of lower limb but a whole-body exercise, muscle strength, and flexibility of UL have also been shown to improve in the aged following Tai Chi (16-18). Furthermore, without the need of supporting body weight, it is believed that the ULs can more easily be relaxed than the lower limbs during Tai Chi (19), which may have the potential to improve spasticity of paretic UL. Therefore, Tai Chi may be a promising UL rehabilitation method. However, the presence of hemiplegia may potentially limit the ability to perform the Tai Chi movements. Adapting Tai Chi to take into account hemiplegia may need to be considered to include it in upper limb rehabilitation post stroke. Moreover, the effectiveness of using adapted Tai Chi movements for UL rehabilitation remains unknown.

Therefore, this study aimed to explore the effects and acceptability of adapted Tai Chi for UL rehabilitation post stroke, including (1) whether the adapted Tai Chi were doable and acceptable by participants; (2) whether the adapted Tai Chi was effective in improving motor function of paretic ULs and activity of life of participants; and (3) participants' perception of the usefulness and ease of practicing the adapted Tai Chi.

Methods

Study design

A single group pre-post study design was used in this study. All participants underwent an 8-week Tai Chi intervention, with a pre and post evaluation and a 4-week follow-up evaluation.

Participants

12 chronic stroke survivors were recruited in this study. The inclusion criteria were: 1) a history of stroke with paretic UL, at least 6 months before the start of the study; 2) UL recovery between stage 2 to 6 for Chedoke-McMaster Arm Impairment Inventory or presence of UL dysfunction as reported by participants in stage 7; 3) able to understand the instructions to participate in assessments and Tai Chi interventions. The exclusion criteria were: 1) currently participating in a program for upper limb rehabilitation, 2) uncontrolled medical problems, 3) significant visual problems like hemianopia that would limit the ability to see the instructor, and 4) moderate or severe aphasia limiting their ability to participate in the study. The study protocol was approved by Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR). Written informed consent was obtained from all participants before the first evaluation.

Intervention

Participants participated in a 60-minute Tai Chi session twice per week for eight weeks. Sessions were delivered individually by a clinician with two years of Tai Chi experience in a research center that is part of the CRIR. A 10-minute Tai Chi home program was also proposed to be done on days without sessions and during the follow-up period. Each session included a 5-minute warm-up sequence, a 5-minute cool down sequence, and 50-minutes of adapted Tai Chi. The Tai Chi intervention consisted of eight forms: two derived from Chen style emphasized shoulder abduction, flexion, and external rotation; six chosen from Yang style had an emphasis on elbow extension, supination of forearm and dorsiflexion of wrist and fingers. The forms from Chen style and two forms from Yang style were basic forms for all participants; other forms from Yang style were used depending on the participants' UL function.

The Tai Chi training followed a gradual, part-to-whole and easy-to-difficult progression. The instructor selected the appropriate adapted Tai Chi forms based on the participants' ability during the sessions. Two key principles were used to adapt the Tai Chi movements for each participant: 1) the participant should be able to practice the Tai Chi movements while relaxing; 2) there should be as much whole-body coordination as possible. According to the impairment level of the involved UL, they practiced UL movements one side at a time or both together. Three lower limb positions were employed including sitting, fixed step and moving step positions based on balance level. Participants were particularly required to relax muscle and joints and focus on movements to help relaxation. Movements were practiced slowly, repeatedly and even segmentally if necessary. For participants with low UL function, only shoulder and elbow movements were emphasized. Active movements were performed with the affected limb even if the range of motion was small, although assistance using the unaffected hand was permitted at the beginning. The clinical reasoning underlying the choice of adaptations has been reported elsewhere (20).

Participant characteristics

The demographic and clinical characteristics of all participants were collected. The Severity Index of Cumulative Illness Rating Scale for Geriatrics was used to document their comorbidities with scores ranging from 0-4 (21). The initial arm and hand motor function stages were evaluated using the Chedoke-McMaster Stroke Assessments (CMSA) (22), which has a range of stages from one to seven. The Modified Ashworth Scale (MAS) (23, 24), a 6-point scale ranging from 0-4, was used to grade initial spasticity level of paralytic ULs. Initial shoulder pain of affected arms was measured using the Visual Analogue Scale (VAS) with scores ranging from 0-10 (25).

Outcome measures

Session attendance and reasons for dropouts were recorded. Number of times and duration of self-practice at home were recorded by participants in a log book. Three outcome measures were collected at three time points: baseline, post-treatment, and follow-up. Motor function of UL was measured with the Fugl-Meyer Assessment upper-limb section (FMA-UL) (26) and the Wolf Motor Function Test (WMFT) (27). Items of FMA-UL are scored on a 3-point ordinal scale and have a maximum score of 66. Previous studies examining FMA-UL has established construct, criterion validity and good reliability (28-31). WMFT is composed of functional ability, time and strength parts, including 15 function and time-based tasks using a 6-point functional ability scale to rate the quality of movement while simultaneously recording performance time, and two strength-based tasks (lifting the weighted limb and grip strength). The maximum time permitted to complete an item of WMFT is 120 seconds. Tasks which cannot be completed within 120 seconds are noted as 121 seconds, and the number of such tasks was used as an outcome variable. Construct, convergent and discriminate validity and good reliability of WMFT in chronic stroke survivors have been reported (27, 32, 33). Activities of daily living (ADL) were measured with the Modified Motor Activity Log (MAL) which consists of 14 specific ADL activities using a 6-point scale to rate the use of their paretic UL (the amount of use, AOU) and quality of movement (QOM) (34). Good criterion validity and reliability of MAL have been reported (34, 35). The evaluations were performed by two evaluators who were not involved in other aspects of the study.

At the follow-up evaluation, a feedback questionnaire, modified from the short feedback questionnaire evaluating virtual reality experience (36), was used to assess participants' perception of the use of Tai Chi, including their perceived usefulness and ease of practicing of Tai Chi. The questionnaire included 18 questions, 10 using a five-point ordinal scale, 3 using a seven-point ordinal scale, and the remaining issues were open-ended questions.

Data analysis

Since the WMFT performance time presented a skewed distribution, a logarithmic transformation was performed to meet assumptions of normality. Logs values were converted back to seconds for better interpretation. To evaluate the treatment's effect on outcome variables, linear mixed models for repeated measures were performed with time as the within-subject factor. Changes between three time points were also analyzed by mixed models. Moreover, based on the functional level of paretic UL, participants were divided into subgroups to visually compare the differences of subgroups effects, though statistical tests could not be performed given the sample size of subgroups. All statistical analyses were conducted using the SPSS statistical program ver. 23.0, and significance was accepted at values of $p<0.05$.

Results

Clinical characteristics.

Twelve chronic stroke survivors participated the study. One withdrew after having participated in three sessions because of lack of public adapted transport services. For the purposes of the exploratory study, the analysis was conducted on the 11 remaining participants. They participated in all 16 sessions of Tai Chi within two months. Their average total self-practice hours over the three months was 16.51±9.21 hours, which was more than recommended. They were on average 59.4±13.0 years old and 22.7±17.7 months after stroke onset (Table 1). Two out of eleven were women, and four had dominant-side hemiparesis. Unexpectedly, three participants were found to participate in other community exercise programs for 20-30 minutes per week. Giving that the time spent was much less than that of the Tai Chi, they were not excluded in the study. Three participants with MAS⩾3 were in stage 2 of CMSA-arm and had received regular Botulinum toxin injection before the intervention.

Efficacy of adapted Tai Chi

The scores of FMA-UL, WMFT and MAL at baseline, post-treatment and follow-up are presented in Table 2. All outcome measures presented improvements from baseline to post-treatment, which were maintained or continued to increase at follow-up. The tests of within-subject effects indicate that there were significant improvements over time on the FMA-UL (p=.009), WMFT functional scale (p=.003), WMFT performance time (p=.048) and MAL AOU scales (p=.02). No significant time effects were shown for MAL QOM scales (p=.095). For the two WMFT strength items, the weight item presented significant time effects (p=.029), while no significant time effects were shown for the grip item (p=.580). The number of tasks on the WMFT that could not be completed by the participants decreased from baseline (5.0) to post-treatment and follow-up (4.0 for both), although this was not significantly different over time (p=.052).

Regarding the effects between time points, FMA-UL, WMFT functional scale and MAL AOU scales had significant improvements immediately after the intervention (p=.042, p=.001, and p=.024 respectively), and these differences persisted at follow-up. The changes of WMFT performance time and WMFT weight item were not significant at post-treatment but were significant at follow-up (p=.015 and p=.010 respectively).

Efficacy of the adapted Tai Chi per subgroup

Eleven participants were stratified into three functional subgroups based on their arm stage on CMSA, including low (stage 2, n=3), middle (stage 3, n=5) and high (stage 6 and better, n=3) UL functional groups. The effects of subgroups on FMA-UL, WMFT and MAL AOU and QOM scales are presented in Figure 1. The middle functional group demonstrated large improvements in these four variables. High and low functional groups had much smaller increases in FMA-UL and WMFT functional scale. The low function group did not show any improvements in the two MAL scales.

Table 1. Demographic and clinical characteristics of participants.

Demographic and clinical characteristics		**Study cohort (n=11)**
Age (years)	Mean(SD)	59.4(13.0)
	Range	41-87
Gender (female) (n, %)		2(18.2)
Dominant-side hemiparesis (yes) (n, %)		4(36.4)
Stroke type (n, %)		
	Ischemic	8(72.7)
	Hemorrhagic	3(27.3)
Time after onset (months)	Mean(SD)	22.7(17.7)
	Range	8-56
CIRS-G Severity Index (⩾3) (n, %)		5(45.5)
Co-rehabilitation (yes) (n, %)		3(27.3)
Technical aids for transfer (n, %)		
	Wheelchair	1(9.1)
	Cane	4(36.4)
	Independent	6(54.5)
Initial shoulder pain (VAS) (>0)		
	n,%	4(36.4)
	Mean(SD)	5.5(3.0)
Spasticity (MAS) (mean, SD)		1.5(1.4)
Initial CMSA stage (arm) (n, %)		
	2	3(27.3)
	3	5(45.5)
	⩾6	3(27.3)
Initial CMSA stage (hand) (n, %)		
	2	5(45.5)
	4 or 5	3(27.3)
	⩾6	3(27.3)

Abbreviations: CIRS-G, Cumulative Illness Rating Scale for Geriatrics; VAS, Visual Analogue Scale; MAS, Modified Ashworth Scale; CMSA, Chedoke-McMaster Stroke Assessments.

Table 2. Effects of the adapted Tai Chi on outcomes from baseline to follow-up.

Outcome variables	Baseline (T1)	Post-treatment (T2)	Follow-up (T3)	Overall p-value &	Differences between T1 and T2 (95% CI)	p-value between T1 and T2 #	Differences between T2 and T3 (95% CI)	p-value between T2 and T3 *	Differences between T1 and T3 (95% CI)	p-value between T1 and T3 ǂ
FMA-UL (max 66)	37.09 (22.2)	42.27 (19.7)	44.46 (19.8)	0.009	5.18 (0.22,10.14)	0.042	2.18 (0.17,4.19)	0.036	7.36 (2.57,12.15)	0.006
WMFT										
Log performance time	1.97 (1.86)	1.79 (1.60)	1.67 (1.64)	0.048	-0.183(-0.422,0.057)	0.127	-0.121(-0.360,0.118)	0.304	-0.304(-0.543,0.064)	0.015
Performance time, seconds¶	7.17	5.99	5.31		0.83 (0.66,1.06)		0.89 (0.70,1.13)		0.74 (0.581,0.94)	
Functional ability (0-5 scale)	2.78 (1.49)	2.98 (1.44)	3.04 (1.47)	0.003	0.20 (0.10,0.30)	0.001	0.06 (-0.002,0.12)	0.058	0.26 (0.13,0.40)	0.001
Weight	5.18 (6.65)	6.36 (7.54)	6.91 (7.42)	0.029	1.182(-0.079,2.443)	0.065	0.545(-0.715,1.806)	0.378	1.727(0.467,2.988)	0.010
Grip	33.08 (31.01)	35.32 (26.32)	34.50 (27.93)	0.580	2.24 (-2.23,6.71)	0.308	-0.82 (-5.29,3.65)	0.706	1.42 (-3.05,5.89)	0.515
MAL										
AOU (0-5 scale)	1.80 (1.83)	2.09 (1.97)	2.14 (1.92)	0.02	0.290(0.042,0.538)	0.024	0.048 (-0.199,0.296)	0.689	0.338(0.091,0.586)	0.01
QOM (0-5 scale)	1.94 (1.93)	2.15 (2.07)	2.22 (1.99)	0.095	0.218(0.001,0.435)	0.049	0.064 (-0.143,0.270)	0.526	0.282(0.007,0.557)	0.045
WMFT No. of tasks >120s	5.00 (5.71)	4.00 (5.08)	4.00 (4.86)	0.052	-1.00 (-1.83,0.18)	0.022	0 (-0.636,0.636)	1.000	-1.00 (-2.12,0.12)	0.077

Abbreviations: FMA-UL, Fugl-Meyer Assessment upper-limb section; WMFT, Wolf Motor Function Test; MAL, Motor Activity Log; AOU, Amount of Use scale; QOM, Quality of Movement scale. ¶ Performance time is a conversion of the logs to original units (seconds). & p-values noted in this column are for overall test of whether the time course is different. # p-values noted in this column are for test for change between baseline and posttreatment. * p Values noted in this column are for test for change between posttreatment and follow-up. ǂ p-values noted in this column are for test for change between baseline and follow-up.

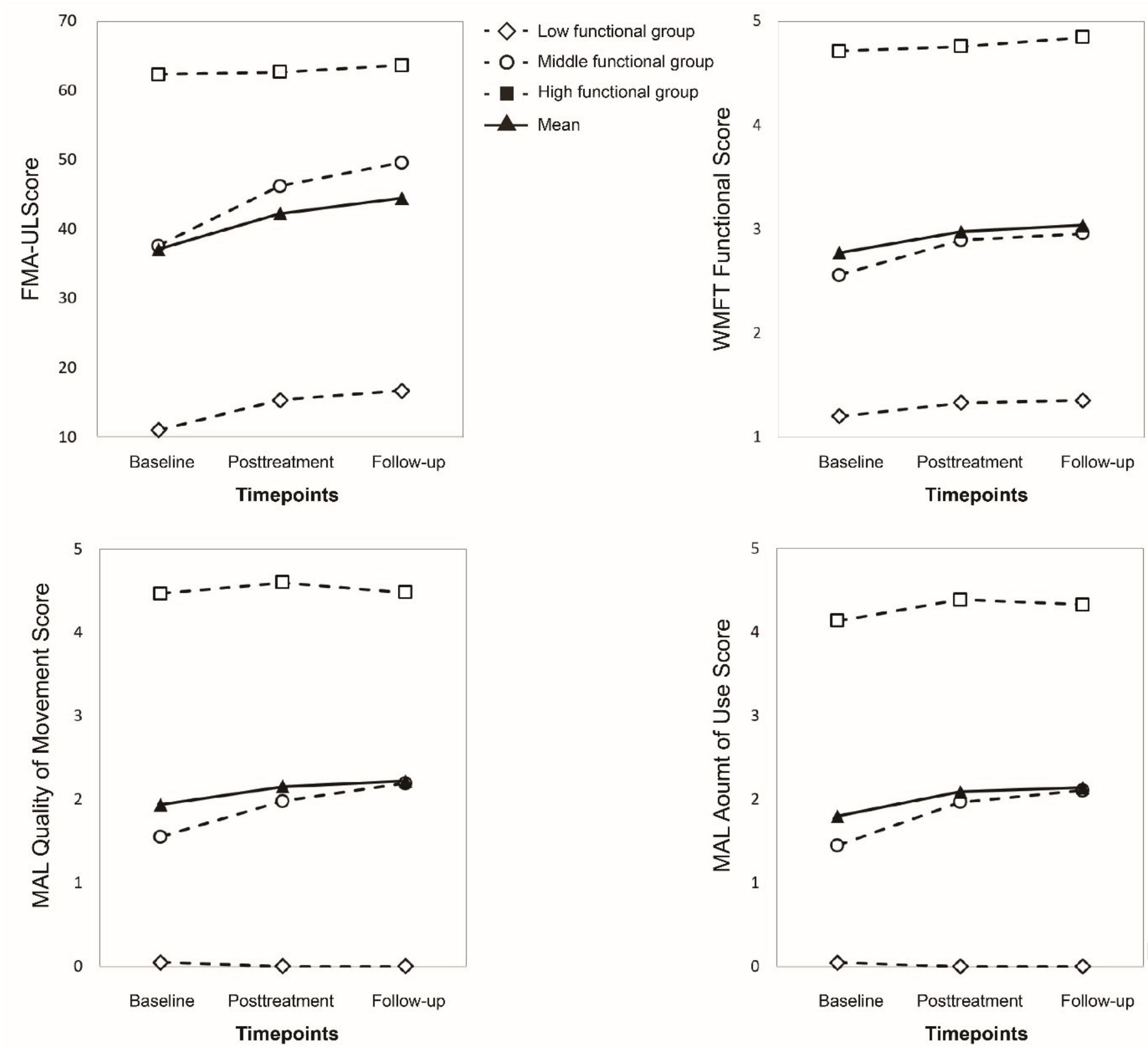

Figure 1. Scores of subgroups in FMA-UL, WMFT Functional Ability Scale, MAL QOM and AOU scales. Abbreviations: FMA-UL, Fugl-Meyer Assessment upper-limb section; WMFT, Wolf Motor Function Test; MAL, Motor Activity Log; AOU, Amount of Use scale; QOM, Quality of Movement scale. Low functional group: arm stage 2 of Chedoke-McMaster Stroke Assessments (CMSA); Middle functional group: arm stage 3 of CMSA; High functional group: arm stage 6 and better of CMSA.

Participants' perception of the adapted Tai Chi

Most participants scored 4 or 5 out of a five-point scale on perceived usefulness questions (Table 3). All participants agreed positively that they enjoyed practicing Tai Chi, wanted to repeat this experience and felt benefits from Tai Chi practice. Nine participants confirmed that they felt in control when performing Tai Chi, and intended to continue practicing at home. The participants in stage 3 and better confirmed they had noted improvements in their arms, including better flexibility and control in movements of the paretic arm. Participants reported that activities of daily life such as eating, driving a car, and handwriting using paretic arms were improved after intervention. Except for the three participants using sitting positions to practice Tai Chi, the other eight participants used standing positions and noted improvements in their lower extremities, including better balance and flexibility of legs. One participant who had had heart by-pass surgery reported that his chest pain stopped after the intervention. Also, one participant noted improvement in his aphasia. None of the participants reported any new discomforts.

Regarding perceived ease of practicing Tai Chi (i.e. how easily participants were able to learn to do the Tai Chi movements), most (n=7/11) of the participants agreed that practicing Tai Chi was easy for them to learn. Sixty-seven percent of the participants in stage 2 and 3 (n=6) indicated no difficulty when practicing Tai Chi using their arms. Four participants who rated "extremely or quite unlikely" how easy it is to practice Tai Chi with their arms were in a range of different stages. All participants were willing to recommend this approach to others. Participants reported most liking the fact that Tai Chi used soft and slow moments. They noted nothing that they disliked about Tai Chi.

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Table 3. Feedback questionnaire of the participants' perception of the adapted Tai Chi

	Question	Not at all 1 and 2	3	A lot 4 and 5
Perceived Usefulness	1-Did you enjoy practicing Tai Chi?	0	0	11
	2- Did the physiotherapist provide clear instructions?	0	0	11
	3-Were you able to follow the physiotherapist?	0	2	9
	4-Did you feel in control while performing Tai Chi?	0	2	9
	5-Would you want to repeat this experience?	0	0	11
	6-Do you think you would be able to exercise Tai Chi regularly at home?	0	2	9
	7-Did you feel any discomfort during these activities?	8	3	0
	8-Did you feel any benefit from these activities?	0	0	11
	9- Did you feel that Tai Chi has improved the function of your arms?	1	2	8
	10-Did you feel that Tai Chi has improved the function of your legs?	2	1	8
	Question	Extremely and quite unlikely	Slightly unlikely, likely and neither	Extremely and quite likely
Perceived Ease of Practice	11- Learning to practice Tai Chi was easy for me.	1	3	7
	12- I found it easy to practice Tai Chi with my arms.	4	3	4
	13- I found it easy to practice Tai Chi with my legs.	3	4	4

Discussion

The objective of this study was to explore the effects and acceptability of Tai Chi used for UL rehabilitation post stroke. Tai Chi was adapted for eleven participants in our study with different UL function and balance level. They attended all the 16 sessions and practiced at home more than recommended. Moreover, the participants showed significant improvements in the motor function of the paretic arm (FMA-UL, WMFT Functional Ability and Performance Time) following the intervention and in the amount of paretic arm use in daily life (MAL AOU scales). Also, the participants confirmed that they perceived Tai Chi to be useful. Overall, the findings from this exploratory study suggest that adapted Tai Chi is acceptable, and there are indications that it is effective in improving paretic UL function. To our knowledge, this is the first study to report the use of Tai Chi on UL rehabilitation after stroke.

Regarding the acceptability of doing Tai Chi, participants with varied characteristics, including severe impaired UL (stage 2 and 3), poor balance, shoulder pain, severe spasticity, and high medical comorbidity burden were capable of practicing their selected adapted Tai Chi movements. Moreover, the adapted Tai Chi was highly appreciated by participants. They not only attended all Tai Chi sessions but also practiced a high amount of Tai Chi at home, in fact, more than what was recommended to them (a total of 16.51±9.21 hours in three months). With respect to participants' perceived ease of practicing Tai Chi, most participants confirmed that they felt in control while performing Tai Chi, and practicing Tai Chi was easy for them to learn. Up to 67% of the participants with severely impaired UL (stage 2 and 3) indicated no difficulty practicing Tai Chi with their arms. All participants intended to continue practicing at home. These findings suggest that adapted Tai Chi is acceptable to chronic stroke patients with UL impairment.

There was a significant improvement in nearly all outcome measures over time except for WMFT grip and MAL QOM scale. One reason which may explain why the latter two measures did not significantly improve may be that these two measures reflect hand function which may not have improved to the same extent as arm function. Motor gains were also corroborated by the decrease in the number of tasks on the WMFT that could not be completed by the participants at both post-treatment and follow-up evaluations, although this was not statistically significant (p=.052). Though there is a significant time effect in WMFT performance time, its p-value is close to 0.05 (p=.048). However, it was a more conservative estimate of the real treatment effects, since tasks which could not be completed within 120 seconds were assigned as 121 seconds, representing a much smaller score than a real one. Overall, these results demonstrate that the adapted Tai Chi had a range of effects, including improving the quality and speed of the paretic arm movements and in the amount of paretic arm use in daily life. Furthermore, the changes of the FMA-UL in the study are larger than its value of minimal clinically important differences (MCID) in chronic stroke (4.25 points) (37), which indicates such changes are clinically significant. Though the MCID values of the WMFT and MAL in chronic stroke have not been reported in previous studies, considering that 72.7 % of the sample in this present study were in stage 2 and 3, that all were in a chronic stage which is relatively stable, the improvements of these two measures in this 8-week exploratory study are likely clinically meaningful.

Furthermore, the improvements on all outcome measures were present post-treatment and persisted or even increased at follow-up. FMA-UL, WMFT functional scale, and MAL AOU scale had even significant improvements immediately after intervention, suggesting that the 8-week Tai Chi practice including 16 sessions and self-practice at home had lasting effects on UL function. Although WMFT performance time and weight did not significantly improve right at post-treatment, there were significant improvements when assessed at follow-up, which may be due to the Tai Chi self-practice at home during follow-up. Therefore, the high dose of Tai Chi practice including 16 sessions and 16.51±9.21 hours of home practice, may have accounted for the noticeable motor gains in the present study. It should be noted that three participants were receiving other UL treatments 20-30 minutes per week during the same period, although the time spent in therapy was much less than that of the Tai Chi. Further studies are needed to provide more robust evidence of Tai Chi intervention.

Given the exploratory nature of this study, we did not include a control group. However, several factors suggest that the findings are not simply due to spontaneous recovery. First, all participants in this study were in a chronic stage post stroke (⩾8 months after stroke onset). Hence, it is unlikely that the gains identified were only due to improvements from spontaneous recovery (38, 39). Furthermore, the changes of the FMA, WMFT functional scale, and performance time in the study are larger than their corresponding values of minimal detectable change at the 95% confidence level (5.2 points, 0.1 points, 0.7 seconds respectively) (40, 41). Therefore, we can be 95% confident that these statistical results were actual differences.

While this study does not allow us to draw inferential statistical conclusions regarding subgroups of participants given the small sample size of subgroups, the results suggest that improvements on the FMA-UL, WMFT functional scale and MAL were smaller for participants in the low and high functional groups as compared to gains in middle functional group (Figure1). For the participants with severe arm paresis the intervention itself may not have lasted sufficiently long and the outcome measures may not have been sufficiently sensitive to detect small changes. For the high functional group, their total self-practice hours in three months were less than those of low and middle UL functional group as previously reported (10.29±4.32hours, 16.6±18.08 hours, and 20.18±11.14 hours respectively) (20), which may contribute to reduced improvements given the lower number of repetitions. Nevertheless, based on the high functional group participants' perspective, they noticed improvements in their UL function, such as better flexibility of arm and hand, better handwriting and driving. Therefore, for high functional level patients, the outcome measures may not be sensitive enough to detect changes in this group. Future research, including longer intervention times and using more sensitive evaluation tools for high and low function subgroups, are required.

Though patients with persistent motor impairment are recommended to perform exercises or activities that aim to increase motor function (42, 43), movement practice is dramatically influenced by severity level in the paretic UL (44). Treatment for severely impaired UL have mainly focused on passive movement training and compensation since there is a global lack of efficacy of interventions in case of this stage of motor recovery (45, 46). However, the results of our study show that the adapted Tai Chi was acceptable for patients in stage 2 and 3. They were able to receive the same duration and frequency of adapted Tai Chi as participants in stage 6 and better. Furthermore, the 8-week Tai Chi intervention was effective in improving motor function of their paretic ULs. Participants in stage 3 even gained large improvements in FMA-UL, WMFT functional scale and MAL scales. Therefore, these results suggest that even individuals with a Chedoke McMaster arm stage lower than 4 could adopt a suitable and adapted restorative exercise program geared towards regaining function in the limb.

For the application for UL rehabilitation, Tai Chi was adapted to take into account the hemiparesis. For example, UL movements were performed one side at a time, and only shoulder and elbow movements were emphasized for the participants with low UL function. Sitting position was used for participants with poor balance. Nevertheless, once their abilities permitted it, participants were encouraged to practice UL movements together and to coordinate these with lower limb movements in standing positions. Therefore, for stroke survivors with sufficient balance, this study provided also an intervention using whole body rehabilitation. The participants who used standing positions improved their balance following the intervention subjectively, which is consistent with other studies that have reported Tai Chi benefits for balance training post stroke (13-15). It should be noted that the use of Tai Chi is limited to balance training post stroke for those with severe balance impairments since the standing positions require a certain level of balance recovery (47). However, Tai Chi can be performed for UL training even in patients with severe balance impairments.

Moreover, the effects of Tai Chi on UL function may also be due to the muscle relaxation aspect, which is the essential feature which differentiates Tai Chi from many other exercises (48). Muscle relaxation during movements was particularly emphasized in this study. Results showed that the three participants with severe spasticity (MAS $\geqslant 3$) were able to follow Tai Chi sessions when given more time for relaxation. Furthermore, they did not receive their regular Botulinum toxin reinjections during the study, and they improved in the FMA-UL and WMFT functional scales (low function group, Figure 1). Interestingly, in an embedded study where an interview of eight participants was performed (49), most of them indicated that they felt that relaxation had helped improve their motor function and life activities. One participant mentioned that his aphasia had greatly improved as a result of relaxation. These data implied that muscle relaxation may play an important role in feasibility and effectiveness of Tai Chi practice. The emphasis on muscle relaxation may be essential for Tai Chi to be used in UL rehabilitation, while benefits of Tai Chi on lower limb and balance may derive from dynamic weight shifting to single-leg standing in different positions (9). Future studies are needed to understand better the role that relaxation plays.

Several reasons may explain the improvements noted following the use of the adapted Tai Chi. First, the adapted Tai Chi allowed participants to perform multiple repetitions of movements.

Even the participants in stage 2 were able to perform a high amount of the adapted movements. Though they gained smaller improvements in motor function following the intervention, their ability to practice Tai Chi is already a meaningful advancement. Furthermore, the adapted Tai Chi was done with muscle relaxation by the participants during the Tai Chi sessions. As mentioned above, muscle relaxation may also play an important role in their motor recovery. Impairments of the affected ULs post-stroke are frequently aggravated by conditioned suppression of its use of the limb that is termed learned disuse (50). The fact that the participants performed the adapted Tai Chi movements with multiple repetition and muscle relaxation may stimulate the use of the affected arms and reduce the effects of learned disuse. Future studies examining the impact on brain activity are warranted.

The main limitation of this study is that there was only one experiment group without control, given the exploratory nature of this study, though we used mixed effects model to analyze the repeated measures. Furthermore, participants with Botulinum toxin injection history before intervention and co-rehabilitation may hinder effects of Tai Chi, therefore randomized controlled trials with strict inclusion criteria are required to provide more robust evidence of Tai Chi effectiveness on UL rehabilitation. Moreover, the interpretation of outcomes was limited by the small numbers in each subgroup. Lastly, the feedback questionnaire was modified from a questionnaire evaluating virtual reality experience, and its validity and reliability have not been established for Tai Chi.

Conclusion

This exploratory study suggests that adapted Tai Chi may be effective and is acceptable for UL rehabilitation by stroke survivors with different impairment levels of paretic UL and balance. Participants demonstrated increased hemiparetic UL functional ability following the intervention. Participants in stage 3 of the Chedoke-McMaster Stroke Assessments-Arm gained the largest effects, while participants in stage 2 and stage 6 and better had smaller improvements. Tai Chi may be a promising UL rehabilitation approach. Further research with large-scale randomized trials is warranted.

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Chapter 6. Discussion

The objective of this study was to explore the feasibility and effects of Tai Chi on upper limb rehabilitation post stroke. Tai Chi was adapted to participants to take into account their current abilities. The clinical reasoning for adapting the Tai Chi was developed to tailor the Tai Chi training to different functional levels of the participants. Participants with varied characteristics including severe impaired upper limb, poor balance, shoulder pain, severe spasticity, high medical comorbidity burden, and the elderly were capable of practicing their selected adapted Tai Chi movements. Moreover, the adapted Tai Chi was well accepted by the participants. They could follow all 16 sessions and practice Tai Chi more than expected at home even in the follow-up month. Regarding the effects of the adapted Tai Chi, the participants gained significant improvements in the motor function of the paretic arm (FMA-UL, WMFT Functional Ability and Performance Time) and in the amount of paretic arm use in daily life (MAL AOU scales) following the Tai Chi intervention. Furthermore, the participants confirmed their perceived usefulness of the adapted Tai Chi. The findings from this exploratory study, therefore, suggest that adapted Tai Chi is feasible, and there are indications that it is effective in improving paretic upper limb function in chronic stroke patients. To our knowledge, this is the first study to report the use of Tai Chi on upper limb rehabilitation after stroke.

6.1 Feasibility of the adapted Tai Chi

6.1.1 Use of the adapted Tai Chi in participants with different impairment level of upper limb

Though it is essential to exercise the hemiparetic arm and hand in all stages of a stroke rehabilitation program (12), movement practice is dramatically influenced by severity level in the paretic upper limb (156). Moreover, traditional upper limb movements of Tai Chi require both upper limbs to move together, which poses more difficulties for participants with the paretic upper limb. Therefore, for severely impaired upper limbs, several strategies were used in the present study to adapt Tai Chi and facilitate its practice. First, Tai Chi movements were modified from being performed both sides bilaterally to one side at a time. Second, practice requirements for the affected side were to emphasize shoulder and elbow movement abilities while not for accuracy. Movements were practiced slowly and even segmentally if necessary. Moreover, though active movements were performed with the affected limb even if the range of motion was small, assistance using the unaffected hand was permitted at the beginning. However, once their abilities permitted it, upper limb movements were done both sides bilaterally.

As a result, three participants who were in stage 2 of CMSA-arm were capable of practicing upper limb movements one side at a time, although ranges of motion of the affected arms were small when doing movements independently. Five participants in stage 3 practiced upper limb movements one side at a time first, and four of them changed to practicing both sides together at the end of 16 sessions. Their affected arms could finish movements independently. Participants in stage 6 and better were able to practice upper limb movements with both sides without modification. Overall, the participants with a CMSA arm stages ranging from 2 to 7 were capable of practicing the adapted Tai Chi movements. Although there were no participants in stage 4 and 5, it is likely that they may also practice upper limb movements from one side at a time to both together, similarly to participants in stage 3, although this remains to be confirmed in future studies. It should be noted that participants in stage 2 in the study had isolated shoulder movements without compensatory the trunk movements before starting the study. Hence, the feasibility of doing Tai Chi, including adapted Tai Chi, with individuals who do not have isolated shoulder movements in stage 2 remains to be tested.

Moreover, the adapted Tai Chi was highly appreciated by participants. They not only attended all Tai Chi sessions but also practiced a high amount of Tai Chi at home, in fact, more than what was recommended to them (a total of 16.51±9.21 hours in three months). Unlike many Tai Chi programs, the adapted Tai Chi in the present study was simple and easy to learn. After the first session, they were able to practice the adapted Tai Chi at home. In the first month, their practice at home was in line with expectations. In the second and follow-up months, most of the participants increased their self-practice time, to an extent far more than expected. Regarding the self-practice amount in subgroups with different paretic upper limb impairment levels, participants in low (stage 2) and middle (stage 3) upper limb functional groups practiced at home for the three months more than high functional (stage 6 and better) group (article1, Figure 2).

Several reasons may explain why participants in stage 2 and 3 practiced more at home than those in the high functional level group (stage 6 and better). It may be that participants in stage 2 and 3 were more motivated since their upper limb function was relatively low, or perhaps they may feel more benefits or improvements of practicing Tai Chi during the study. Another reason may be that they were more available to include Tai Chi practice into a routine since they were less engaged in daily activities. Future studies should examine the reasons for compliance and non-compliance to better address the barriers.

With respect to participants' perceived ease of use of Tai Chi, most of the participants confirmed that they felt in control when performing Tai Chi, and intended to repeat practicing at home. 66.7% of the participants in stage 2 and 3 (n=6) indicated no difficulty practicing Tai Chi with their arms. Hence, the perceived difficulty of the participants seemed not to be related to upper limb functional stages. No new discomforts were mentioned while practicing movements. These findings confirmed that the adapted Tai Chi was feasible for and acceptable to chronic stroke patients with upper limb impairment.

6.1.2 Use of the adapted Tai Chi in participants with different balance impairment level

Traditional Tai Chi forms use standing position with moving steps, which poses difficulties for participants with paretic lower limbs and insufficient balance to practice Tai Chi. Hence, apart from moving step positions, sitting or fixed step position were used in the study depending on participants' balance level. Sitting position was used in participants whose balance was insufficient to support standing. Participants were required to only practice upper limb movements. One subject who used a wheelchair and two participants who used a cane in the study practiced Tai Chi in a sitting position. Though sitting Tai Chi has been reported to be used in persons with spinal cord injuries to improve muscle strength of upper limb (33), to our knowledge, it is the first time it has been reported in stroke rehabilitation. No falls were recorded when practicing Tai Chi at home or during sessions during the whole study. Thus this exploratory study suggests that Tai Chi can be safe when appropriately adapted to the participants' abilities. Furthermore, sitting position may also help persons with poor upper limb function to better concentrate on upper limb practice, without taking into account lower limb movements. It was also used in the study for those who had sufficient balance but poor upper limb function.

For persons with sufficient balance to support standing, two standing positions including fixed step and moving step positions were used. Taking upper limb ability into consideration, moving step position required both high upper limb function and sufficient balance, while fixed step position could be used in persons with low upper limb function. Moreover, since this study focused on upper limb rehabilitation, to make a balance between feasibility of upper limb and coordination with lower limb, a combination of lower limb positions was applied in the study by a part-to-whole and easy-to-difficult way, taking challenge and ease of exercise into consideration. As a result, sitting and fixed step positions were used for participants with enough balance but low upper limb function (5 participants in stage 2 or 3), fixed and moving step positions used for participants with enough balance and high upper limb function (3 participants in stage 6 and better).

Consequently, by adapting lower limb positions to the participants' balance level, all participants were capable of practicing Tai Chi. However, it should be noted that this study assessed balance level as being able or not to maintain the standing position during the intervention. Except for the three participants using sitting positions to practice Tai Chi, the other eight participants using standing positions reported improvements in their lower extremities, including better balance and flexibility of legs, which is consistent with other studies that have reported Tai Chi benefits for balance training post stroke (26-28). The clinical reasoning applied in this study included lower limb position. Therefore it may be relevant for rehabilitation of both upper and lower limbs. Future studies should pursue the clinical reasoning in order to include more detailed balance evaluation data in the underlying clinical reasoning.

6.1.3 Use of the adapted Tai Chi in participants with shoulder pain and spasticity

Shoulder pain may also be a potential barrier for the paretic arms to perform Tai Chi movements. Previous studies also showed that the external rotators are muscles commonly involved in shoulder pathologies, movements which emphasize on shoulder external rotation and abduction are recommended to prescribe in rehabilitation for the treatment of shoulder pain (8, 142). Two basic forms derived from Chen style were selected in the study for the purpose of practicing external rotation and abduction of shoulder joint. Four participants in the study had shoulder pain in the affected upper limb before intervention with a mean VAS of 5.5±3. The shoulder pain appeared during movement but did not interfere with Tai Chi movements. Moreover, their shoulder pain decreased right after intervention and at the end of follow-up (VAS 3±2.8, 2.5±2.5 respectively). Participants noted that their shoulder pain had decreased especially after these two basic forms. Participants without initial shoulder pain did not feel any shoulder pain during the whole study. The total self-practice over the three months was similar in the should pain group (VAS>0) and no shoulder pain group (VAS=0) (article2, Figure 4). These results show that shoulder pain in the paretic arm did not limit Tai Chi practice, and in fact, pain decreased following intervention.

Spasticity following stroke is a common reason for restraining movements of the paretic upper limb. Three participants who had severe spasticity (MAS ≥3) were able to practice upper limb movements one side at a time, though they required more time to relax before starting a movement as well as a segmental pause during movement, and active range of motion of the affected arm was small when doing movements independently. Although they received Botulinum toxin injections regularly prior to participating in this study, it was not felt to be medically required throughout the course of the study. The total self-practice time over three months for the moderate-to-severe spasticity group (MAS ≥ 2) was even more than those in the slight or no spasticity group (MAS<2). The results indicate that spasticity is in fact not a reason for not practicing Tai Chi. We have to point out that we did not evaluate the spasticity level of participants following intervention; future research is warranted to provide more evidence of the effect of Tai Chi on spasticity.

In conclusion, the adapted Tai Chi was accepted and able to be practiced by participants with different impairment levels of the upper limb, with poor balance, with shoulder pain, and with severe spasticity. Hence, low upper limb function, insufficient balance, spasticity and shoulder pain may not be valid reasons for not encouraging Tai Chi, although further studies with larger sample sizes and wider range of functional abilities post-stroke are needed.

6.2 Effects of adapted Tai Chi

6.2.1 Overall effects of adapted Tai Chi

The tests of within-subject effects indicate that there are significant time effects in the outcome measures including FMA-UL, WMFT functional scale, WMFT performance time, WMFT weight and MAL AOU scales, with the exception of WMFT grip and MAL QOM scales. In other words, there was significant improvement in nearly all upper limb outcome measures over time. The reason why the latter two measures did not gain significant changes may be that these measures likely reflect better improvement of hand function, which may not occur at the same rate at arm function. Motor gains were also corroborated by the decreased in the number of tasks on the WMFT that could not be completed by participants at both post-treatment and follow-up evaluations, although this was not statistically significant ($p=.052$). Overall, these results demonstrate that the adapted Tai Chi had a range of effects, including improving the quality and speed of the paretic arm movements and in the amount of paretic arm use in daily life. Since it is the first study to use Tai Chi as an intervention for upper limb rehabilitation post stroke, we cannot compare the results to any other studies using the same intervention. Also, it is challenging to compare these results with other upper limb rehabilitation methods due to heterogeneity of study sample and varying outcome measures (51). However, previous studies indicate that interventions may not lead to meaningful functional use of the arm in the case of chronic stroke patients with severe motor impairment of upper limb even when provided with long-term rehabilitation training (12, 58). Considering that 72.7 % of the sample in this present study were in stage 2 and 3, that all were in a chronic stage, the improvements in this 8-week exploratory study were clinically meaningful.

Furthermore, the improvements on all outcome measures were present post-treatment and persisted or even increased at follow-up, although all participants were more than 8 months post-stroke. FMA-UL, WMFT functional scale, and MAL AOU scales had significant improvements immediately after intervention which persisted at follow-up, suggesting that the 8-week Tai Chi practice including 16 sessions and self-practice at home had a lasting impact on upper extremity function. Although WMFT performance time and weight did not significantly improve right after the intervention, there were significant improvements when assessed at follow-up, which may be due to the Tai Chi self-practice at home during follow-up. In the study, participants were asked to practice 10 minutes of Tai Chi at home on days without sessions. Results showed that the home program was doable and acceptable by participants right after the first session. The total amount of their self-practice at home was almost the same as those of all 16 sessions. Altogether, the high dose of Tai Chi practice including 16 sessions and 16.51±9.21 hours of home practice, may have accounted for the noticeable motor gains in the present study. This kind of self-administered exercise program by patients during their off-therapy time was also recommended and proved effective in improving arm-hand function in other studies (49). It should be noted that the data for self-practice at home was patient-reported; more objective data to record the amount of participants' practice at home may be needed in the future.

With respect to participants' perceived usefulness of the adapted Tai Chi, most participants scored 4 or 5 for all questions relating to this concept. All participants agreed positively that they enjoyed practicing Tai Chi, wanted to repeat this experience and felt benefits from Tai Chi practice. Most participants confirmed they had noted improvements in their arms, including better flexibility and control in movements of the paretic arm. They reported that activities of daily life such as eating, driving a car, and handwriting using paretic arms were improved after intervention. All participants were willing to recommend this procedure to others. As a whole, participants confirmed the usefulness of the adapted Tai Chi.

6.2.2 Effects of adapted Tai Chi in subgroups with different impairment level of upper limb

The efficacy of the adapted Tai Chi on subgroups divided by impairment level of upper limb was descriptively compared; statistical comparisons of subgroups of participants was not feasible since the sample sizes were too small to compare the differences between subgroups by inferential statistics. Nevertheless, the findings suggest that gains on the FMA-UL, WMFT functional scale and MAL were smaller for participants in the low (stage 2) and high functional groups (stage 6 and better) as compared to gains in middle functional group (stage 3) (Article2, Figure1). In other words, participants in stage 3 had the largest gains for these outcome variables. For the low functional group, the intervention itself may not have lasted sufficiently long, and the outcome measures may not have been sufficiently sensitive to detect small changes. For the high functional group, they reported practicing less at home than the other two groups, which may contribute to reduced improvements given the lower number of repetitions. Nevertheless, based on the high functional group participants' perspective, they noticed improvements in their upper limb function, such as better flexibility of arm and hand, better handwriting and driving. Therefore, for high functional level patients, the outcome measures may not be sensitive enough to detect changes in this group. Future research, including longer intervention times and using more sensitive evaluation tools for high and low function subgroups, are required.

Although patients with persistent motor impairment are recommended to perform exercises or activities to improve their voluntary motor control and muscle strength (46), it is hard to increase active movement in the severely impaired arm of stroke survivors (157). Methods of stroke rehabilitation for severely impaired upper limb (less than stage 4 of CMSA-arm) have focused mainly on passive movement training or compensatory training of the nonparetic arm, since the evidence suggests that there is a global lack of efficacy of interventions in case of this stage of motor recovery (57, 59). However, the results of this study show that the adapted Tai Chi was feasible and acceptable to be practiced by patients in a Chedoke McMaster score of stage 2 and 3. Furthermore, the 8-week Tai Chi intervention was effective in improving motor function of their paretic upper limbs. The participants in stage 3 could even gain large improvements in FMA-UL, WMFT functional scale and MAL scales. Therefore, these results suggest that even individuals with a paretic upper limb in stage 4 or less could adopt a suitable and adapted restorative exercise program geared towards regaining function in the limb.

6.3 Principles underlying adaptation of Tai Chi

Two key principles were used in the study when adapting the Tai Chi training for each participant: 1) the participant should be able to practice the Tai Chi movements while relaxing; 2) there should be as much whole-body coordination as possible. As discussed previously, to take into account the hemiparesis, the practice of upper limb movements was modified from both together to one side at a time, and traditional standing position of Tai Chi was replaced by sitting position for participants without sufficient balance to support standing. Consequently, the adapted Tai Chi was doable by participants with severe hemiparesis. Also, relaxation and coordination, two important principles of Tai Chi, were also integrated into the adaptation of Tai Chi movements.

6.3.1 Relaxation

Relaxation is the essential feature which differentiates Tai Chi from many other exercises (17). Thus, even when Tai Chi is adapted, it is indispensable to keep the relaxation component to maintain the essence as in the original Tai Chi styles. Muscle relaxation during Tai Chi practice was particularly emphasized in this study. Participants were asked to focus on the movements for the purpose of mental concentration, thus helping muscular relaxation. Relaxation during movements was prioritized over the precision of movements. Results showed that three participants with severe spasticity were able to follow Tai Chi sessions when given more time for relaxation. They did not receive regular Botulinum toxin reinjections during the study, as had previously been the case, and they improved in the FMA-UL and WMFT functional scale (low function group, Figure 1). The total self-practice hours of the subgroup in MAS≥2 was not less than those of subgroup in MAS<2. This may be a consequence of the relaxation approach used. To our knowledge, Tai Chi as a mind-body therapy which emphasizes both mind and body relaxation, it is the first time that its effect on spasticity has been reported.

It should be noted that spasticity level after the intervention was not evaluated since this study planned to measure spasticity level before intervention as one of the participants' characteristics, to explore whether spasticity was an influencing factor which would constrain the Tai Chi practice. Also, there are no tools to evaluate the extent of relaxation. However, an embedded study which included interviews with eight participants was performed (158). Most of the participants stated that relaxation had helped improve their motor function and life activities. In addition, one participant mentioned that his aphasia had greatly improved as a result of relaxation. These data implied that relaxation may play an important role in the feasibility and effectiveness of Tai Chi practice. Muscle relaxation practice in the present study may reduce spasticity and thus promote Tai Chi practicing and functional gains. Future studies are needed to provide more scientific evidence of the relaxation effects of Tai Chi.

Muscle relaxation training has been suggested as a means to control the involuntary muscular activity of cerebral palsy patients (32). However, little research has been conducted to examine the effects of relaxation training in restoring motor function after stroke. During Tai Chi practice, upper limbs are thought to be easier to be relaxed than lower limbs as there is no need to support the body weight (72). Given that the benefits of Tai Chi on lower limb and balance may derive from dynamic weight shifting to single-leg standing in different positions, it may be more important to emphasize muscle relaxation with Tai Chi when used in upper limb rehabilitation (85). Future studies are needed to understand better the role that relaxation plays. Furthermore, given that Tai Chi forms in this study were able to be adapted into simple movements combined with relaxation practice, physiotherapy movements coupled with relaxation practice may also have similar effects as adapted Tai Chi, thus may be a future direction of stroke rehabilitation.

6.3.2 Coordination

In addition to encouraging that the participants practice Tai Chi movements while relaxing, participants were encouraged to practice upper limb movements together and to coordinate these with lower limb movements using standing positions once their abilities are permitted. Coordination is another important feature of Tai Chi, which emphasizes whole-body movements in a coordinated way as much as possible. The principle of coordination can also increase the difficulty of practice and thus challenge participants to improve their functional ability, which is an important strategy for improving motor control after stroke. In the present study, upper limb movements were encouraged to be practiced starting with one side at a time to bilaterally for participants in stage 3. Results indicate that four of the five participants in stage 3 progressed to practicing both arms together at the end of 16 sessions, and participants in stage 6 and better could practice both arms from the start. As opposed to what Van Delden has proposed that bilateral arm training after stroke (118), our results suggest that ipsilateral Tai Chi movements were feasible and preferential for severe to moderate arm paresis, whereas bilateral Tai Chi movements were suitable for mild arm paresis. The reason may be that the Tai Chi bilateral movements in this study were different (i.e. the arm movements performed by each side were different), which may require more bilateral coordination than other bilateral arm training techniques. This may particularly pose difficulty for stroke patients with severe to moderate arm paresis.

Previous studies have reported that practicing bilateral movements improved the recovery of affected upper limb (116), the stimulation of the intact hemisphere may assist the recovery of the injured hemisphere through neural networks (159). Therefore, to perform Tai Chi movements bilaterally may be one of the factors leading to motor function improvements of the paretic upper limb, future studies are needed to provide more scientific evidence of bilateral training effects of Tai Chi. Moreover, considering that upper limb paresis impacts the ability of stroke patients to use the affected hand to perform bimanual tasks in daily activities (119), bilateral arm training of Tai Chi may also improve bimanual coordination of upper limbs. However, bimanual coordination ability in this study was not evaluated, and this remains to be confirmed in future studies.

Coordination of Tai Chi movements also involves upper limb and trunk to move sequentially. During practicing Tai Chi, shoulder movements need to be isolated from trunk movements. The trunk usually needs to go opposite direction compared with shoulder movements (i.e. the trunk goes backward when the shoulder moves forward). Reaching movements made with the paretic upper limb in the moderately to severely impaired stroke patients, are often leading to develop compensatory trunk movements when reaching for objects (160), trunk restraint therapy can enable functional reach practice by restraining this atypical trunk movement (120). In this study, based on Tai Chi forms, participants were asked to practice upper limb movements by intentionally restraining the trunk compensation. All participants, including even those at stage 2, were able to have isolated shoulder movements without compensatory the trunk movements before starting the study. This training is similar to the traditional trunk restraint therapy but without the use of the external device, which may encourage the recovery of more normal reaching patterns and function in the paretic upper limb. Future studies are needed to provide scientific evidence of its efficacy.

Regarding standing positions, fixed and moving step positions were used when upper limb movements were performed which in standing positions of sufficient stability. The coordination of the upper and lower (non-homologous) limbs is more challenging than bilateral coordination of upper limbs, which may constrain the practice of upper limb movements with relaxation. Therefore, a balance is needed to achieve between principles of relaxation and coordination. In this study, the order for coordination ability from weak to strong is moving step, fixed step and sitting positions, while their capacity to help concentrate on upper limb practice with relaxation is in reverse order. Consequently, a combination of lower limb positions was used in the study to take into account both relaxation of paretic upper limb and coordination of the whole body. These lower limb three positions were combined from an easy-to-difficult way to make participants gradually increase their practice ability, taking challenge and ease of exercise into consideration. For example, participants with good balance but a poor upper limb function used a combination of sitting and fixed step positions. One participant with the arm in stage 6 and with sufficient balance, had difficulty coordinating the upper and lower limb while in the standing position at the beginning (data not reported); future studies may take coordination and learning ability into account to provide a complete clinical reasoning picture.

6.4 Underlying mechanism of improvements following Tai Chi intervention

Several reasons may explain the improvements noted following the use of the adapted Tai Chi. First, the adapted Tai Chi allowed participants to perform multiple repetitions of movements. Even the participants in stage 2 were able to perform a high number of repetitions of the adapted movements. Though they made smaller in motor function following the 8-week intervention, their ability to practice Tai Chi is already a meaningful advancement. Furthermore, the adapted Tai Chi was done with relaxation by the participants during the Tai Chi sessions. As mentioned previously, relaxation may also play an important role in their motor recovery. Third, the principle of coordination enhanced the practice difficulty and challenge participants to increase their ability of practice, which may help to improve motor control of the paretic upper limb. As we know, impairments of the affected upper limbs of chronic stroke patients are frequently aggravated by conditioned suppression of the use of the limb, which is called learned non-use (5). Therefore, the fact that the participants performed the adapted Tai Chi movements with multiple repetition, relaxation, and coordination, may stimulate the use of the affected arms and reduce the effects of learned non-use, thus could help to promote positive changes in brain structure and function even in the chronic stage after stroke. Hence, Tai Chi is a promising rehabilitation strategy for upper limb rehabilitation.

6.5 Study strengths and limitations

Given the exploratory nature of this study, a single group pretest-posttest design was used in the study, without including a control group. Therefore, improvements associated with spontaneous recovery may be a threat to internal validity of the study. It should be noted that a multiple baseline pretest-posttest using a reversal AABA design which is likely to rule out such bias was considered. Considering that all participants were in a chronic stage and their arm function would be relatively stable (34), only one pre-treatment test was performed in the study to decrease the burden of evaluations for participants. Moreover, participants in this study may get Tai Chi practice into a routine after the 8-week intervention including 16 sessions and self-practice at home, and their self-practice in the follow-up month may also provide valuable information for the feasibility and acceptability of Tai Chi on upper limb rehabilitation. Therefore, this study did not use a reversal AABA design which requires participants to stop practicing Tai Chi after the intervention, but allowed them to continue the practice in the follow-up month. Consequently, one-group pretest-posttest design with one pre-treatment test and two post-treatment tests was used in this exploratory study.

To maximize the power of the study, a statistical design in which linear mixed models for repeated measures were performed with time as the within-subject factor. In such a design, both pre-treatment and post-treatment scores were dependent variables, and the treatment by time interaction was the main assessment of the intervention. Thus, such model would offer more power than a general single group pretest-posttest design with only one pre-treatment and one pre-treatment measurements. However, further randomized controlled trials are required to provide more rigorous data concerning Tai Chi efficacy on upper limb rehabilitation.

Two factors supported by evaluation tools suggest that the findings are not simply due to measurement error or chance and have a good internal validity. First, test-retest reliability studies of the FMA-UL (35), WMFT (150) and MAL (153) in persons with long-term stroke disabilities have shown that scores of these measures are stable over approximately 2-week intervals. Second, the changes of the FMA, WMFT functional scale, performance time in the study are larger than their corresponding values of minimal detectable change (MDC) at the 95% confidence level (161, 162). MDC values in outcome measures indicate whether changes are actual differences or merely resulting from measurement error or chance (163). Therefore, we can be 95% confident that these statistical results were actual differences.

Another potential threat to internal validity of the study is a statistical regression since the sample of the study included participants with both high (stage 6 and better) and low (stage 2) function of the paretic upper limb. Since the pre-test scores of these participants were extremely high or low, there may be a tendency for these scores to move towards the mean. Given this, participants in the study were further divided into three subgroups based on the functional level of paretic upper limb, to compare the differences of subgroups effects. Though statistical tests could not be performed given the sample size of subgroups, such interpretation of outcomes among subgroups was helpful for better understanding the effects of Tai Chi.

On the other hand, the sample in this study contained participants with both high and low function of the paretic upper limb which may increase the external validity of the study. However, the generalization of Tai Chi's feasibility and efficacy on upper limb rehabilitation in other settings or populations was limited due to the small and convenience sample of the study. There were no participants in stages 4 and 5 to allow for a complete portrait of the clinical reasoning for adapting Tai Chi, and this study did not provide detailed balance evaluation data for choosing lower limb positions. Future studies with a larger sample size may take more situations into accounts such as coordination and learning ability, to provide a complete clinical reasoning picture. Moreover, the external validity of the study may also be influenced by Tai Chi instructors with different teaching experiences. For example, explaining clearly the importance of key principles of practicing Tai Chi to participants and guiding them to perform better muscle relaxation, may lead to different results with different Tai Chi instructors. Designing a more standard Tai Chi intervention may be important for future studies.

6.6 Use of Tai Chi in the future

This exploratory study puts forward for the first time that adapted Tai Chi is feasible, effective and acceptable for upper limb rehabilitation. The underlying clinical reasoning was identified in the study to adapt Tai Chi to different upper limb impairment levels and balance abilities of participants. Relaxation and coordination principles of Tai Chi were integrated into the adaptation of Tai Chi. The detailed clinical reasoning for adapting Tai Chi and the preliminary effects of adapted Tai Chi in the present study, provide recommendations for Tai Chi use by clinicians and researchers. Randomized controlled trials using long-term Tai Chi intervention are required in the future to provide more rigorous results of Tai Chi on upper limb rehabilitation. Moreover, participants in this study were all in a chronic stage post stroke. It will be important to examine the safety and efficacy of adapted Tai Chi for upper limb rehabilitation with subacute stroke survivors.

As mentioned previously, since the clinical reasoning allowed for lower limb training of participants with sufficient balance, it may be used not only for upper limb rehabilitation but also for rehabilitation of both upper and lower limbs in the future. However, it should be noted that the use of Tai Chi is more limited for lower limb rehabilitation post stroke in those with severe balance impairments since standing positions are needed to gain a certain level of balance recovery. Nevertheless, Tai Chi can be performed for upper extremity training even in patients with severe balance impairments.

Since this is the first study to explore the use of Tai Chi for upper limb rehabilitation, Tai Chi sessions were delivered individually to better identify the clinical reasoning underlying adaptation for each participant. For efficient clinical use of Tai Chi in the future, Tai Chi sessions may be delivered in groups stratified by impairment level of the upper limb and balance. Moreover, given that Tai Chi forms in the present study were able to be adapted into simple movements combining relaxation practice, to integrate physiotherapy movements with relaxation practice may also have similar effects as adapted Tai Chi, thus may be a future direction of stroke rehabilitation without the need of learning Tai Chi by clinicians. Finally, integrating Tai Chi with telerehabilitation approaches may also be a promising solution to increase accessibility to such services.

Chapter 7. Conclusions

This exploratory study suggests that adapted Tai Chi is feasible, effective and acceptable for upper limb rehabilitation by stroke survivors with different impairment levels of paretic upper limb and balance. The clinical reasoning for adapting Tai Chi based on relaxation and coordination principles can provide recommendations for clinicians and researchers. Low upper limb function, insufficient balance, spasticity, and shoulder pain do not appear to be sufficient reasons for not practicing Tai Chi. Participants demonstrated increased hemiparetic upper limb functional ability following the intervention. Tai Chi may be a promising upper limb rehabilitation approach. Future research is recommended to provide a complete portrait of the clinical reasoning for adapting Tai Chi, and research using large-scale randomized trials evaluating Tai Chi as a rehabilitation intervention for upper limb rehabilitation at different stages of stroke recovery is warranted.

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Appendix A

Ethics Certificate

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Consent Form

Comité d'éthique de la recherche
des établissements du CRIR
CRIR

Montréal, le 18 décembre 2014

Madame Dahlia Kairy, pht, Ph.D.
CRIR - site de l'IRGLM
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○ Centre de réadaptation Constance-Lethbridge
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○ Institut de réadaptation Gingras-Lindsay-de-Montréal
○ Institut Nazareth et Louis-Braille
○ Institut Raymond-Dewar

Partenaires
○ Centre de réadaptation en déficience physique Le Bouclier
○ Centre de réadaptation Estrie
○ Centre de réadaptation MAB-Mackay

Objet : Votre demande de modification pour le projet de recherche intitulé « Un programme d'exercices basés sur le Tai Chi dispensé par téléréadaptation comparé à des visites à domicile chez des personnes ayant eu un AVC de retour à domicile sans réadaptation intensive : un essai clinique randomisé de non-infériorité »
Notre dossier : CRIR-788-1212

Madame,

À la suite de l'analyse de la demande de modification que vous nous avez soumise, le Comité d'éthique de la recherche des établissements du CRIR tient à vous informer qu'il vous autorise à poursuivre le projet cité en rubrique, tout en lui apportant l'amendement suivant :

- Ajout d'un volet additionnel au projet : pour vérifier la perception des personnes ayant eu un AVC face au Tai Chi pour la récupération du membre supérieur. Des séances de tai chi en personne seront effectuées pour documenter la perception des participants de l'utilisation du Tai Chi pour le membre supérieur.

  Les critères d'inclusion sont :
  - avoir eu un AVC ;
  - être suivi en externe ou ayant eu congé de la réadaptation ;
  - avoir une limitation au niveau du membre supérieur (Chedoke entre 3-6).

  Les participants à ce volet seront vus à l'IRGLM deux fois par semaine (selon un horaire qui leur convient, et en tenant compte de leur horaire en externe), pour une séance d'une heure de TaiChi. Une évaluation pré-post du membre supérieur (Wolf, Chedoke McMaster du bras, questionnaire de satisfaction) sera effectuée.

.../2

Le nouveau formulaire de consentement (version anglaise et française du 18 décembre 2014) répond aux exigences éthiques en vigueur.

Veuillez recevoir, Madame Kairy, mes cordiales salutations.

Me Anik Nolet
Coordonnatrice à l'éthique de la recherche
des établissements du CRIR

AN/cl

c.c. : Isabelle David, IRGLM

FORMULAIRE M
Titre: Un programme d'exercices basés sur le Tai Chi dispensé par téléréadaptation comparé à des visites à domicile chez des personnes ayant eu un AVC de retour à domicile sans réadaptation intensive : un essai clinique randomisé de non-infériorité
 # Dossier: CRIR-788-1212

Veuillez cocher et remplir les cases correspondantes aux modifications que vous voulez apportées

Une fois que vous aurez terminé le formulaire M, n'oubliez pas d'aller ajouter les nouveaux documents au dossier!

☑ **Modification au protocole de recherche**

S'il y a de nouveaux participants, veuillez inscrire le nombre dans les cases suivantes

Nombre de participants à recruter au total :	0
CRCL	0
INLB	0
IRGLM	10
CRLB	0
IRD	0
HJR	0
CR Le Bouclier	0
CR La RessourSe	0
CR Estrie	0
CMR	0
CRMM	0
IRDPQ	0

APPROUVÉ PAR LE CÉR DES ÉTABLISSEMENTS DU CRIR
LE : 18 décembre 2014

Veuillez remplir les champs suivants pour justifier ces modifications

Critères d'inclusion :	Volet additionnel : recruter les personnes ayant eu un AVC et suivi en externe ou ayant eu congé de la réadaptation, avec une limitation au niveau du membre supérieur (Chedoke entre 3-6) (dans le projet actual ceux qui ont eu de la réadaptation sont exclus).
Critères d'exclusion :	
Modalités de recrutement :	À partir des dossiers aux archives et par la coordonnatrice de programme (ou le/la clinicienne contacte identifiée)
Justifiez la modification :	

Ceci est un volet additionnel qui a été ajouté pour vérifier la perception des personnes ayant eu un AVC face au TaiChi pour la récupération du membre supérieur. Des séances de tai chi en personne seront effectuées pour documenter la perception des participants de l'utilisation du Tai Chi pour le membre supérieur.

Veuillez remplir la case suivante s'il y a modification des tâches expérimentales

Précisez : Les participants à ce volet seront vu à l'IRGLM deux fois par semaine (selon un horaire qui leur convient, et en tenant compte de leur horaire en externe), pour une séance d'une heure de TaiChi. Une évaluation pré-post du membre supérieur (Wolf, Chedoke McMaster du bras, questionnaire de satisfaction) sera effectuée.

☑ **Modification au formulaire de consentement**

Précisez la nature de cette modification, s'il y a lieu et ne pas oublier de soumettre la nouvelle version du formulaire de consentement avec les changements surlignés en jaune une fois que aurez terminer le formulaire M :

Précisez : Le formulaire initial a été repris et modifié car pour ce volet les participants ne participent pas par téléréadaptation ni par thérapie en face-à-face à domicile, mais reçoivent de la réadaptation par Tai Chi en personne au centre de réadaptation (IRGLM). il s'agit d'un projet parallel pour documenter plus particulièrement la perception face au tai chi pour le membre supérieur. La nature de la participation a donc été ajustée.

☐ **Modification du budget ou du financement**

☑ **Modification au questionnaire ou autre document de recherche à être complété**

Précisez la nature de cette modification, s'il y a lieu et ne pas oublier de soumettre le ou les nouveaux questionnaires utilisés une fois que aurez terminer le formulaire M :

Le seul test qui a été ajouté est un questionnaire de satisfaction face au Tai-Chi.

Précisez :

Centre de recherche
interdisciplinaire
en réadaptation
du Montréal métropolitain

INSTITUT DE RÉADAPTATION
Gingras-Lindsay-de-Montréal

INFORMATION SHEET
AND RESEARCH CONSENT FORM FOR THE PARTICIPANT

Title:	**Satisfaction with and feasibility of Tai-chi for upper extremity rehabilitation post-stroke**
Principal investigators:	Dahlia Kairy, pht, Ph.D. (University of Montreal, School of Rehabilitation, Center for Interdisciplinary Research in Rehabilitation of Greater Montreal -CRIR) Rose Shujan Pan (master's student, University of Montreal, School of Rehabilitation, Center for Interdisciplinary Research in Rehabilitation of Greater Montreal -CRIR)
In collaboration with:	Michel Tousignant, pht, Ph.D. Hélène Corriveau, pht, Ph.D. Research Center on Aging (RCoA) of the Health and Social Services Centre – University Institute of Geriatrics of Sherbrooke, University of Sherbrooke

We are asking you to participate in this research project because you have had some paralysis of the upper extremities following a stroke. Before accepting to participate in this project, please take the time to read, to understand and to consider all information provided. If you choose to accept to participate in the research project, you will need to sign the consent form that can be found at the end of this document. You will be provided with a copy of the completed document for your files.

This information sheet & consent form explains the aim of the research project, procedures, advantages, potential risks & inconveniences, and who to contact if needed. There might be words or concepts that you may not understand. Please take the time to ask all necessary questions to the local principle investigator or other personnel involved in the project and ask them to explain any words or information that is not clear to you.

APPROUVÉ PAR LE CER
[...]SSEMENTS DU CHIR
LE: 18 décembre 2014

RESEARCH PROJECT AIM & OBJECTIVES

This study aims to evaluate the satisfaction with and feasibility of offering a Tai Chi based exercise program for upper limbs function in people who have weakness of the arm following a stroke.

Research project aim and objectives:
The principle investigator and the co-investigators will:

- Verify the level of satisfaction with a Tai-Chi program
- Verify the feasibility of doing Tai-Chi with people who have arm weakness following a stroke
- Verify the impact of the program on arm recovery

We expect to recruit a total of 10 participants from the Institut de réadaptation Gingras-Lindsay de Montréal (IRGLM).

RESEARCH PROJECT PROCEDURES

Your participation in this research project will last a total of four (4) months.

You will participate in three (3) evaluations (T1, T2, T3), each one (1) hour in duration. The evaluations will take place at the Institut de réadaptation Gingras-Lindsay de Montréal (IRGLM) research center. Each time, we will assess the physical function of your upper extremities (arms and hands), quality of life, attitude towards Tai Chi and your satisfaction of services received.

You will receive two (2) treatment sessions per week at the IRGLM, each 45-60 minutes in length, for eight (8) weeks.

The following describes how the project will proceed.

1. Enrolment

- If you accept to participate in the research project, a member of the research team will meet with you to have you sign the consent form after having reviewed the information pertaining to the project. At this time, the member of the research team will evaluate your impairments of the arm and quality of life. You will continue to receive all the rehabilitation services you were receiving.

2. During the 8 weeks of treatment (2 months)

- You will participate in two (2) Tai Chi sessions per week, each 45-60 minutes in duration for a period of eight (8) weeks, offered by a person trained in Tai Chi.
- The exercise program comprises movements that are a combination of arm and leg movements inspired by Tai Chi.

3. Right after your 8 weeks of treatment

- You will participate in a second evaluation (T2) which will be similar to the first evaluation.

- You will be asked to go to the IRGLM research center to take part in this second evaluation (T2).

4. <u>One month after your 8 weeks of treatment</u>

- You will undergo a third, and final evaluation (T3).
- Again, you will be asked to go to the IRGLM research center to complete the evaluation.

POTENTIAL RISKS DUE TO YOUR PARTICIPATION

- Some exercises (e.g. weight transfers) may put you at risk of falling.
- The exercises will be chosen so as not to place you in a risky situation and we will ensure that a family member or member of the research team will be able to assist you, if needed, during your supervised treatment sessions.

POTENTIAL INCONVENIENCES DUE TO YOUR PARTICIPATION

- You may feel fatigued during or following the evaluation or treatment sessions. Rest periods will be provided as needed.
- The amount of time required for the interventions, and the fact that you may be accompanied by a relative if needed could be an inconvenience to you, as you will be expected to be available twice a week for 45-60 minutes each time for a period of eight (8) weeks.
- You will need to go to the IRGLM three (3) times for evaluations during the study, specifically for this project.

ADVANTAGES THAT MAY RESULT FROM YOUR PARTICIPATION

It may be possible that you gain a personal benefit due to your participation in this research project such as an improvement of your upper limb function. This however cannot be guaranteed.

Furthermore, the results obtained from this study will help advance knowledge in the field of upper extremity rehabilitation post-stroke

VOLUNTARY PARTICIPATION AND POSSIBILITY OF WITHDRAWL

Your participation in this research project is completely voluntary and you have the right to refuse to participate completely. You are equally allowed to withdraw from this project at any time without having to provide a reason. If you do choose to withdraw, please advise the principle investigator or one of the team members of the project.

Your decision to not participate in this research project or to withdraw from the study will not impact the quality of care and services that you have the right to receive. It will also not negatively impact your relations with the principle investigator of the project or any of the therapists.

ACCESS TO YOUR MEDICAL FILE

On occasion, the project managers may need to consult your rehabilitation chart at the IRGLM to become familiar with your medical history, your current medical monitoring and your medications since they can all affect your condition. By participating in this study, we request that you authorize the persons responsible for this study to have access to your medical file. If you choose "No" in this section, you can still participate in the research project.

Yes ☐ No ☐

AUTHORIZATION TO USE DIGITAL RECORDINGS

On occasion, the principle investigators of the project, Dahlia Kairy and Rose Shujuan Pan, may use recordings of the sessions (including the videos of Tai chi exercise and evaluation) for scientific and educational purposes (e.g. scientific articles, rehabilitation student courses). It could be possible to recognize you in these videos. By participating in this study, we request that you allow the person responsible for the project to record some of the sessions and present the digital recordings in these circumstances.

Yes ☐ No ☐

CONFIDENTIALITY

All the personal information collected for your subject during the study will be codified to ensure their confidentiality. Only the members of the research team will have access. However, with the purpose of controlling the research project control, your research file could be consulted by a person authorized by the ethics committee for the research of CRIR institutions or by the Ethics Unit of the Ministry of Health and Social Services of Quebec, which adheres to a strict privacy policy. The responsible person of the study will conserve these data at the IRGLM for a period of 5 years from the end of the project, after that, they will be destroyed. In case of presentation of results of the research or of publication, nothing will be mentioned about your identification.

COMPENSATION

You will receive a compensation of $60 to cover any expenses and inconveniences incurred during your travels to participate in the study. If you withdraw from the study or are withdrawn prior to completion, you will receive an amount proportional to your participation in the evaluations in the study (i.e. $20 per evaluation).

CLAUSE OF RESPONSIBILITY

By agreeing to participate in this study, you do not waive any of your rights, nor release the principle investigator, the local principle investigator, the co-investigators or the institutions associated with the research project of any of their civil and professional responsibilities.

FUTURE STUDIES

It may be possible that the results obtained in this project lead to further research studies. In such an event, do you authorize the person responsible for this research project to contact you to ask if you would be interested in participating in the new research project?

Yes ❑ No ❑

If you agree, you accept to be contacted in the time frame of:

❑ 1 year

❑ 2 years

❑ 3 years

If you desire to withdraw your authorization in the future, you can do so at any time by contacting Rose Pan Shujuan

PERSONS TO CONTACT

If you have any questions concerning the research project or if you have a problem that you feel is related to your participation in the research project, please feel free to contact the principle investigator of the research project or one of the members of her team at the following numbers:

- Prof. Dahlia Kairy, Principle Investigator:

For any question related to your rights as a participant in a research project, of if you have any formal complaints or comments, you can contact:

- The local Commissioner of complaints and quality of services at the Institut de réadaptation Gingras-Lindsay de Montréal

ETHICAL ISSUES

The Research Ethics Board of the CRIR institutions have approved this project and ensure continued monitoring. We are committed to submitting any revision or modification of the research protocol or information sheet and consent form for approval.

If you would like to reach a member of the Research Ethics Board of the CRIR institutions, you can contact Maître Anik Nolet

CONSENT

I, the undersigned, declare that I have fully read the information sheet and consent form provided, especially in relation to the nature of my participation in the research project and the extent of risks that may arise. I recognize that the project has been explained to me, all of my questions have been answered and I have been given time to make a decision.

I, the undersigned, voluntarily accept to provide consent to participate in this project.

____________________	____________________	__________
Name of participant (Block Letters)	Signature of participant	Date
____________________	____________________	__________
Name of the person who obtained the consent (Block Letters)	Signature of the person who obtained the consent	Date

RESPONSIBILITY OF THE LOCAL PRINCIPLE INVESTIGATOR

I, the undersigned, along with my research team certify to respect what was agreed upon in this information sheet and consent form and that a signed and dated copy was provided to the participant.

I, the undersigned, also certify to respect the right of the participant to withdraw from the study at any time and to inform the participant of any new knowledge acquired during the course of the project that could affect their decision to continue to participate.

____________________	____________________	__________
Name of the Local Principle Investigator (Block Letters)	Investigator Signature	Date

Appendix B

Chedoke-McMaster Stroke Assessments

Severity Index of Cumulative Illness Rating Scale for Geriatrics

Modified Ashworth Scale

Visual Analogue Scale

Chedoke-McMaster Stroke Assessments (CMSA)

Chedoke-McMaster Stroke Assessment
SCORE FORM Page 2 of 4
IMPAIRMENT INVENTORY: STAGE OF RECOVERY OF ARM AND HAND

ARM and HAND: Start at Stage 3. Starting position: sitting with forearms in lap or supported on a pillow in a neutral position, wrist at 0° and fingers slightly flexed. Changes from this position are indicated by underlining. Place an X in the box of each task accomplished. Score the highest Stage in which the client achieves at least two Xs.

ARM

1 ☐ not yet Stage 2

2 ☐ resistance to passive shoulder abduction or elbow extension
☐ facilitated elbow extension
☐ facilitated elbow flexion

3 ☐ touch opposite knee
☐ touch chin
☐ shoulder shrugging > ½ range

4 ☐ extension synergy, then flexion synergy
☐ shoulder flexion to 90°
☐ elbow at side, 90° flexion: supination, then pronation

5 ☐ flexion synergy, then extension synergy
☐ shoulder abduction to 90° with pronation
☐ shoulder flexion to 90°: pronation then supination

6 ☐ hand from knee to forehead 5X in 5 sec
☐ shoulder flexion to 90°: trace a vertical figure 8
☐ arm resting at side of body: raise arm overhead with full supination

7 ☐ clap hands overhead, then behind back 3X in 5 sec
☐ shoulder flexion to 90°: scissor in front 3X in 5 sec
☐ elbow at side, 90° flexion: resisted shoulder external rotation

☐ **STAGE OF ARM**

HAND

1 ☐ not yet Stage 2

2 ☐ positive Hoffman
☐ resistance to passive wrist or finger extension
☐ facilitated finger flexion

3 ☐ wrist extension > ½ range
☐ finger or wrist flexion > ½ range
☐ supination, thumb in extension: thumb to index finger

4 ☐ finger extension then flexion
☐ thumb extension > ½ range, then lateral prehension
☐ finger flexion with lateral prehension

5 ☐ finger flexion, then extension
☐ pronation: finger abduction
☐ hand unsupported: opposition of thumb to little finger

6 ☐ pronation: tap index finger 10X in 5 sec
☐ pistol grip: pull trigger, then return
☐ pronation: wrist and finger extension with finger abduction

7 ☐ thumb to finger tips, then reverse 3X in 12 sec
☐ bounce a ball 4 times in succession, then catch
☐ pour 250 ml. from 1 litre pitcher, then reverse

☐ **STAGE OF HAND**

Severity Index of Cumulative Illness Rating Scale for Geriatrics (CIRS-G)

CUMULATIVE ILLNESS RATING SCALE FOR GERIATRICS (CIRS-G)

Miller, Paradis, and Reynolds 1991

PATIENT____**AGE**_______________

RATER____**DATE**______________

Instructions: Please refer to the CIRS-G Manual. Write brief descriptions of the medical problem(s) th justified the endorsed score on the line following each item. (Use the reverse side for more writing space).

RATING STRATEGY

0 - No Problem
1 - Current mild problem or past significant problem
2 - Moderate disability or morbidity/requires "first line" therapy
3 - Severe/constant significant disability/"uncontrollable" chronic problems
4 - Extremely Severe/immediate treatment required/end organ failure/severe impairment in function

	SCORE
HEART..	______
VASCULAR..	______
HEMATOPOIETIC..	______
RESPIRATORY..	______
EYES, EARS, NOSE AND THROAT AND LARYNX..	______
UPPER GI..	______
LOWER GI..	______
LIVER..	______
RENAL..	______
GENITOURINARY..	______
MUSCULOSKELETAL/INTEGUMENT..	______
NEUROLOGICAL..	______
ENDOCRINE/METABOLIC AND BREAST..	______
PSYCHIATRIC ILLNESS..	______
TOTAL NUMBER CATEGORIES ENDORSED..	______
TOTAL SCORE..	______
Severity Index: (total score/total number of categories endorsed)..	______
Number of categories at level 3 severity..	______
Number of categories at level 4 severity..	______

Modified Ashworth Scale (MAS)

Scoring based on the classification below:

0 No increase in muscle tone

1 Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part(s) is moved in flexion or extension

1+ Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM

2 More marked increase in muscle tone through most of the ROM, but affected part(s) easily moved

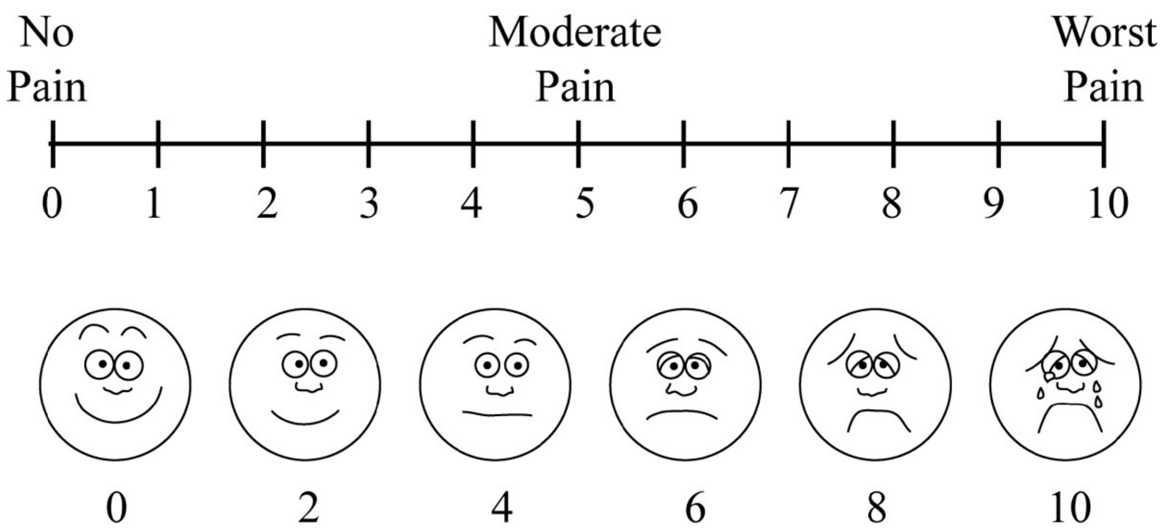
3 Considerable increase in muscle tone, passive movement difficult

4 Affected part(s) rigid in flexion or extension

General Information:

- Place the patient in a supine position
- If testing a muscle that primarily flexes a joint, place the joint in a maximally flexed position and move to a position of maximal extension over one second
- If testing a muscle that primarily extends a joint, place the joint in a maximally extended position and move to a position of maximal flexion over one second
- The patient should be instructed to relax.

Visual Analogue Scale (VAS)



Instructions: Please make on the line to show the amount of shoulder pain that you feel

Appendix C

Fugl-Meyer Assessment upper-limb section

Wolf Motor Function Test

Motor Activity Log

Short-feedback questionnaire

Fugl-Meyer Assessment upper-limb section (FMA-UL)

A. UPPER EXTREMITY, sitting position				
I. Reflex activity		none	can be elicited	
Flexors: biceps and finger flexors		0	2	
Extensors: triceps		0	2	
	Subtotal I (max 4)			
II. Volitional movement within synergies, without gravitational help		none	partial	full
Flexor synergy: Hand from contralateral knee to ipsilateral ear. From extensor synergy (shoulder adduction/ internal rotation, elbow extension, forearm pronation) to flexor synergy (shoulder abduction/ external rotation, elbow flexion, forearm supination).	Shoulder retraction	0	1	2
	elevation	0	1	2
	abduction (90°)	0	1	2
	external rotation	0	1	2
	Elbow flexion	0	1	2
	Forearm supination	0	1	2
Extensor synergy: Hand from ipsilateral ear to the contralateral knee	Shoulder adduction/internal rotation	0	1	2
	Elbow extension	0	1	2
	Forearm pronation	0	1	2
	Subtotal II (max 18)			
III. Volitional movement mixing synergies, without compensation		none	partial	full
Hand to lumbar spine	cannot be performed, hand in front of SIAS	0		
	hand behind of SIAS (without compensation)		1	
	hand to lumbar spine (without compensation)			2
Shoulder flexion 0°-90°	immediate abduction or elbow flexion	0		
elbow at 0°	abduction or elbow flexion during movement		1	
pronation-supination 0°	complete flexion 90°, maintains 0° in elbow			2
Pronation-supination	no pronation/supination, starting position impossible	0		
elbow at 90°	limited pronation/supination, maintains position		1	
shoulder at 0°	complete pronation/supination, maintains position			2
	Subtotal III (max 6)			
IV. Volitional movement with little or no synergy		none	partial	full
Shoulder abduction 0 - 90°	immediate supination or elbow flexion	0		
elbow at 0°	supination or elbow flexion during movement		1	
forearm pronated	abduction 90°, maintains extension and pronation			2
Shoulder flexion 90°- 180°	immediate abduction or elbow flexion	0		
elbow at 0°	abduction or elbow flexion during movement		1	
pronation-supination 0°	complete flexion, maintains 0° in elbow			2
Pronation/supination	no pronation/supination, starting position impossible	0		
elbow at 0°	limited pronation/supination, maintains extension		1	
shoulder at 30°-90° flexion	full pronation/supination, maintains elbow extension			2
	Subtotal IV (max 6)			
V. Normal reflex activity evaluated only if full score of 6 points achieved on part IV				
biceps, triceps,	0 points on part IV or 2 of 3 reflexes markedly hyperactive	0		
finger flexors	1 reflex markedly hyperactive or at least 2 reflexes lively		1	
	maximum of 1 reflex lively, none hyperactive			2
	Subtotal V (max 2)			
	Total A (max 36)			

B. WRIST support may be provided at the elbow to take or hold the position, no support at wrist, check the passive range of motion prior testing		none	partial	full
Stability at 15° dorsiflexion elbow at 90°, forearm pronated shoulder at 0°	less than 15° active dorsiflexion dorsiflexion 15°, no resistance is taken maintains position against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 90°, forearm pronated shoulder at 0°, slight finger flexion	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Stability at 15° dorsiflexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	less than 15° active dorsiflexion dorsiflexion 15°, no resistance is taken maintains position against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Circumduction	cannot perform volitionally jerky movement or incomplete complete and smooth circumduction	0	1	2
	Total B (max 10)			

C. HAND support may be provided at the elbow to keep 90° flexion, no support at the wrist, compare with unaffected hand, the objects are interposed, active grasp		none	partial	full
Mass flexion from full active or passive extension		0	1	2
Mass extension from full active or passive flexion		0	1	2
GRASP				
A – flexion in PIP and DIP (digits II-V) **extension in MCP II-V**	cannot be performed can hold position but weak maintains position against resistance	0	1	2
B – thumb adduction 1-st CMC, MCP, IP at 0°, scrap of paper between thumb and 2-nd MCP joint	cannot be performed can hold paper but not against tug can hold paper against a tug	0	1	2
C - opposition pulpa of the thumb against the pulpa of 2-nd finger, pencil, tug upward	cannot be performed can hold pencil but not against tug can hold pencil against a tug	0	1	2
D – cylinder grip cylinder shaped object (small can) tug upward, opposition in digits I and II	cannot be performed can hold cylinder but not against tug can hold cylinder against a tug	0	1	2
E – spherical grip fingers in abduction/flexion, thumb opposed, tennis ball	cannot be performed can hold ball but not against tug can hold ball against a tug	0	1	2
	Total C (max 14)			

D. COORDINATION/SPEED after one trial with both arms, blind-folded, tip of the index finger from knee to nose, 5 times as fast as possible		marked	slight	none
Tremor		0	1	2
Dysmetria	pronounced or unsystematic slight and systematic no dysmetria	0	1	2
		> 5s	**2 - 5s**	**< 1s**
Time	more than 5 seconds slower than unaffected side 2-5 seconds slower than unaffected side maximum difference of1 second between sides	0	1	2
	Total D (max 6)			

TOTAL A-D (max 66)	

Motor Activity Log (MAL)-14

	Did the activity		Why did you not do the activity or use the affected arm as you did the activity			
Activity	**Scor e QO M**	**Scor e AOU**	**I used the unaffected arm entirely**	**Someon e else did it for me**	**I never do that activity, with or without help from someone else**	**I sometimes do that activity, but did not have the opportunity since the last time I answered these questions**
1. Hold book						
2. Use towel						
3. Pick up glass						
4. Brush teeth						
5. Shave/Make-up						
6. Open door with key						
7. Write/Type						
8. Steady self						
9. Put arm through clothing						
10. Carry object						
11. Grasp fork/spoon						
12. Comb hair						
13. Pick up cup						
14. Button clothes						

Amount of Use (AOU)	
0	Did not use weaker arm (never)
1	Occasionally used weaker arm, but only very rarely (very rarely)
2	Sometimes used weaker arm but did the activity most of the time with stronger arm (rarely)
3	Used weaker arm about half as much as before the stroke (half pre-stroke)
4	Used weaker arm almost as much as before the stroke (3/4 pre-stroke)
5	Used weaker arm as often as before the stroke (same as pre-stroke)
Quality of Movement (QOM)	
0	The weaker arm was not used at all for that activity (never)
1	The weaker arm was moved during that activity but was not helpful (very poor)
2	The weaker arm was of some use during that activity but needed help from the stronger arm or moved very slowly or with difficulty (poor)
3	The weaker arm was used for the purpose indicated but movements were slow or were made with only some effort (fair)
4	The movements made by the weaker arm were almost normal, but were not quite as fast or accurate as normal (almost normal)
5	The ability to use the weaker arm for that activity was as good as before the stroke (normal)

Wolf Motor Function Test (WMFT)

Subject's Name: ______________________________ Date: ____________________

Test (check one): Pre-treatment __________ Post-treatment __________ Follow-up ___

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

Scoring of WMFT functional Ability Scale

0 – Does not attempt with upper extremity (UE) being tested.

1 –UE being tested does not participate functionally; however, attempt is made to use the UE. In unilateral tasks the UE not being tested may be used to move the UE being tested.

2 – Does, but requires assistance of the UE not being tested for minor readjustments or change of position, or requires more than two attempts to complete, or accomplishes very slowly. In bilateral tasks the UE being tested may serve only as a helper.

3 – Does, but movement is influenced to some degree by synergy or is performed slowly or with effort.

4 – Does; movement is close to normal *, but slightly slower; may lack precision, fine coordination or fluidity.

5 – Does; movement appears to be normal *.

(*) For the determination of normal, the less-involved UE can be utilized as an available index for comparison, with pre-morbid UE dominance taken into consideration.

Short Feedback Questionnaire –Tai Chi

Perceived Usefulness

Please circle the number that best reflects your response:					
Part 1:	Not at all				A lot
1- Did you enjoy practicing Tai chi?	1	2	3	4	5
2- Did the physiotherapist provide clearly the instruction?	1	2	3	4	5
3- Did you succeed in following the physiotherapist?	1	2	3	4	5
4- Did you feel in control during performing Tai Chi?	1	2	3	4	5
5- Would you want to repeat this experience?	1	2	3	4	5
6- Do you think you would be able to exercise Tai chi regularly at home?	1	2	3	4	5
7- Did you feel any discomfort during these activities?	1	2	3	4	5
8- Did you feel any benefit from these activities?	1	2	3	4	5
9- Did you feel that Tai chi has improved the function of your arms?	1	2	3	4	5
10- Did you feel that Tai chi has improved the function of your legs?	1	2	3	4	5

If you felt any discomfort, please specify____

____

____

If you felt any benefit, please specify____

____

____

If you felt any improvement of your arms, please specify________________________________

____

____

If you felt any improvement of your legs, please specify ________________________________

____

____

Perceived Ease of Use

11- Learning to practice Tai chi was easy for me.

likely	Extremely	quite	slightly	neither	slightly	quite	extremely	unlikely

12- I found it easy to practice Tai chi with my arms.

likely	Extremely	quite	slightly	neither	slightly	quite	extremely	unlikely

13- I found it easy to practice Tai chi with my legs.

likely	Extremely	quite	slightly	neither	slightly	quite	extremely	unlikely

14- Indicate what things you liked about Tai chi.

15- Would you recommend this procedure to others?

16- Indicate what things you disliked about Tai chi.

17- Was there something jarring or unexpected about this activity? If so, what?

18- Is there anything you recommend to be changed about Tai chi?

Thanks for your taking part in this study!