

# Adapted Tai Chi Enhances Upper Limb Motor Control in Chronic Stroke Patients: A Pilot Study

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## Abstract

**Background:** Tai Chi has been reported as beneficial for improving balance post stroke, yet no study examined the use of Tai Chi for upper limb rehabilitation. The objective of this study was to evaluate the efficacy and acceptability of Tai Chi for upper limb rehabilitation post stroke.

**Methods:** Twelve chronic stroke survivors with a persistent paretic upper limb underwent 60-min adapted Tai Chi sessions twice a week for eight weeks and a 4-week follow-up. A 10-min Tai Chi home program was recommended for the days without sessions. Session attendance and duration of self-practice at home were recorded. 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 Tai Chi 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 Tai Chi. They attended all 16 sessions and practiced Tai Chi at home more than recommended (a total of 16.51  $\pm$  9.21 hours). Participants demonstrated significant improvement over time in the FMA-UL ( $p=0.009$ ), WMFT functional scale ( $p=0.003$ ), WMFT performance time ( $p=0.048$ ) and MAL Amount of Use scale ( $p=0.02$ ). Moreover, participants confirmed the usefulness and ease of practicing the adapted Tai Chi.

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

**Keywords:** Stroke; Rehabilitation; Tai Chi; Upper extremity; Efficacy; Acceptability

## Introduction

Functional impairment of the upper limb is reported in approximately 85% of stroke survivors [1], 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 of the arm and only 5-20% will achieve full recovery of arm function [2]. Though upper limb recovery has been found to continue even in chronic stroke stages [3], the effects of current treatments for arm weakness are shown to be modest [4]. Moreover, long-term rehabilitation services are limited to a large proportion of chronic stroke patients after returning home [5,6]. 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 [7-9]. Through consistent weight shifting between two feet [10], Tai Chi has been broadly reported as beneficial for improving balance and for fall prevention in the elderly [11-13]. Recently, there is some evidence supporting its benefits in improving balance in chronic stroke patients [14-16]. However, its use for upper limb rehabilitation remains unknown.

Given that Tai Chi is not only a lower-limb exercise but a whole-body exercise, upper limb muscle strength and flexibility have also been shown to improve in the aged following Tai Chi [17-19]. Furthermore, without the constraint of needing to support the body weight, it is believed that the upper limbs can more easily be relaxed than the lower limbs during Tai Chi [20], which may have the potential to

improve motor function of the paretic upper limb. Therefore, Tai Chi may be a promising upper limb rehabilitation method. However, the presence of hemiplegia may potentially limit the ability to perform the Tai Chi movements. Similarly, shoulder pain and severe spasticity of the affected arm may impact on Tai Chi practice. 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 considered to include it in upper limb rehabilitation post stroke. Although sitting Tai Chi has been reported to be used in persons with spinal cord injuries to improve muscle strength of upper limb [21], little is known about how to adapt Tai Chi for paretic upper limbs. Moreover, the effectiveness and acceptability of using adapted Tai Chi movements for upper limb rehabilitation remain unknown.

Therefore, this study aimed to explore the effects and acceptability of using adapted Tai Chi for upper limb rehabilitation post stroke, including (1) whether the adapted Tai Chi were doable and acceptable by

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participants; (2) whether the adapted Tai Chi was effective in improving motor function of the paretic upper limb and activity of daily living 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 community-dwelling chronic stroke survivors 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 on the Chedoke-McMaster Arm Impairment Inventory [22], 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 institutional review board of the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR). Written informed consent was obtained from all participants before the first evaluation.

### Tai Chi intervention

Participants underwent a 60-min Tai Chi session twice a 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-min Tai Chi home program was also proposed to be done on days without sessions and during the follow-up period (i.e. weeks 9-12). Each session included a 5-min warm-up sequence, a 5-min cool down sequence, and 50-min of adapted Tai Chi.

The Tai Chi intervention consisted of eight forms selected from traditional styles. Two forms deriving from Chen style [23], known as Front Cloud Hands and Side Cloud Hands, emphasized shoulder abduction, flexion, and external rotation. Six forms chosen from Yang style [24] 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 (see supplementary information). 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 movements of upper and lower limbs based on the participants' ability during the sessions. Two key principles were sequentially followed 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 upper limb, they practiced upper limb movements one side at a time or both together. Two lower limb positions were employed including sitting and standing

positions based on balance level. Standing position with stepping was used in participants with sufficient balance. They could also use a standing position without actually stepping if stepping was difficult for them. Sitting position was used in participants whose balance was insufficient to support standing or in participants who could not use standing position during the whole session.

Participants were specifically asked 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 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 permitted at the beginning.

### Clinical 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 [25]. 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) [26,27], a 6-point scale ranging from 0-4, was used to grade initial 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 at the end of follow-up period.

**Shoulder pain and falls:** The Visual Analogue Scale (VAS) [28] with scores ranging from 0-10 was used to measure shoulder pain of the affected arm at baseline, post-treatment and 4-week follow-up. Good concurrent validity, test-retest reliability and sensitivity to change of the VAS have been reported [29-31]. The number of falls during Tai Chi sessions and self-practice at home were recorded.



**Outcome measures:** Three outcome measures were collected at three time points: baseline, post-treatment, and follow-up. Motor function of upper limb was measured with the Fugl-Meyer Assessment upper-limb section (FMA-UL) [32] and the Wolf Motor Function Test (WMFT) [33]. 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 [34-37]. 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 sec. Tasks which cannot be completed within 120 sec are noted as 121 sec, 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 [33,38,39]. 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 upper limb (the amount of use, AOU) and quality of movement (QOM) [40]. Good criterion validity and reliability of MAL have been reported [40,41]. 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 [42], 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 questions were open-ended questions.

### Data analysis

Frequencies were calculated to check extreme values. Participants' self-practice times were compared between groups of different level of upper limb function. Since the WMFT performance time presented a skewed distribution, a logarithmic transformation was performed to meet assumptions of normality. 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 upper limb, 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. The dropout rate was 8.3%. For the purposes of the exploratory study, the analysis was conducted on the 11 remaining participants. They were on average  $59.4 \pm 13.0$  years old and  $22.7 \pm 17.7$  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 less than 30 min per week. Given that the time spent was much less than that of the Tai Chi, they were not excluded from the study. Three participants with  $MAS \geq 3$  were in stage 2 of CMSA-arm and had received regular Botulinum toxin injection before the intervention. They did not receive any injections during the study period when reinjection time came. Comorbidities included hypertension ( $n=5$ ), diabetes mellitus ( $n=2$ ), heart bypass surgery ( $n=1$ ), kidney and pancreas transplantation ( $n=1$ ), bilateral total knee replacement ( $n=1$ ),

| 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                         | 08-56               |
| CIRS-G Severity Index ( $\geq 3$ ) (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)             |
| Spasticity (MAS) (mean, SD)                           |                               | 1.5(1.4)            |
| Initial CMSA stage (arm) (n, %)                       | 2                             | 3(27.3)             |
|   | 3                             | 5(45.5)             |
|   | $\geq 6$                      | 3(27.3)             |
| Upper limb movements practiced by participants (n, %) | One side at a time            | 8(72.7)             |
|   | Both together                 | 3(27.3)             |
| Lower limb positions used by participants (n, %)      | Sitting position              | 3(27.3)             |
|   | Sitting and standing position | 5(45.5)             |
|   | Standing position             | 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 1: Demographic and clinical characteristics of participants.

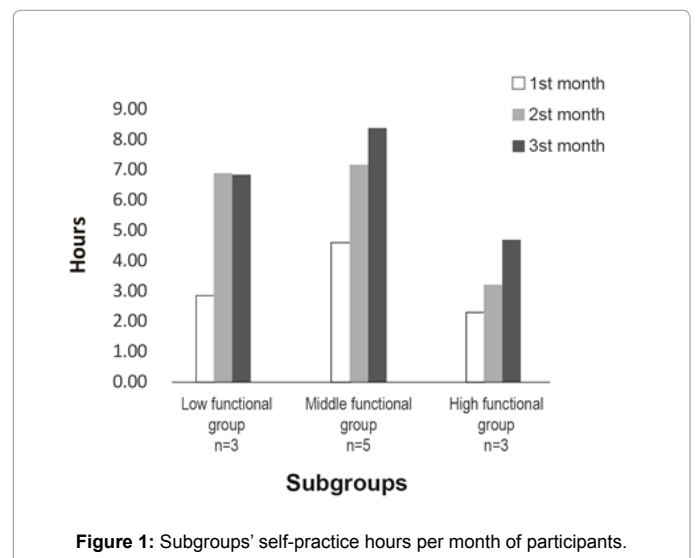


Figure 1: Subgroups' self-practice hours per month of participants.

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 in the two-month period. After the first session, they were able to begin practicing the adapted Tai Chi at home. The mean self-practice time of participants in the first month was  $3.5 \pm 1.8$  h, and this increased significantly in the second and third month by  $6.0 \pm 3.7$  and  $6.97 \pm 4.7$  h respectively. They 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) upper limb functional groups. The total self-practice time over the three months (intervention plus follow-up) of the low and middle upper limb functional groups was more than that of the high upper limb functional group (16.6 h ± 18.1 h, 20.2 h ± 11.1 h, and 10.3 h ± 4.3 h respectively). The subgroups' self-practice hours per month are presented in Figure 1.

### Shoulder pain and falls

Four participants had initial 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. Their shoulder pain decreased with the 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. No fall was recorded throughout the study.

### 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=0.009), WMFT functional scale (p=0.003), WMFT performance time (p=0.048) and MAL AOU scales (p=0.02). No significant time effects were shown for MAL QOM scales (p=0.095). For the two WMFT strength items, the weight item presented significant time effects (p=0.029), while no significant time effects were shown for the grip item (p=0.580). 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=0.052).

Regarding the effects between time points, FMA-UL, WMFT functional scale and MAL AOU scales had significant improvements immediately after the intervention (p=0.042, p=0.001, and p=0.024 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=0.015 and p=0.010 respectively).

### Efficacy of the adapted Tai Chi per subgroup

The effects of subgroups on FMA-UL, WMFT and MAL AOU and QOM scales are presented in Figure 2. 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.

### 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 only 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

| 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 † |
|--------------------------------|---------------|---------------------|----------------|-------------------|--|-----------------------------|--|-----------------------------|--|-----------------------------|
| 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                       |
| <b>WMFT</b>                    |               |                     |                |                   |  |                             |  |                             |  |                             |
| 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                       |
| 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)                    | 0.01                        |
| Grip                           | 33.08 (31.01) | 35.32 (26.32)       | 34.50 (27.93)  | 0.58              | 2.24 (-2.23,6.71)                      | 0.308                       | -0.82 (-5.29,3.65)                     | 0.706                       | 1.42 (-3.05,5.89)                      | 0.515                       |
| <b>MAL</b>                     |               |                     |                |                   |  |                             |  |                             |  |                             |
| 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                           | -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.

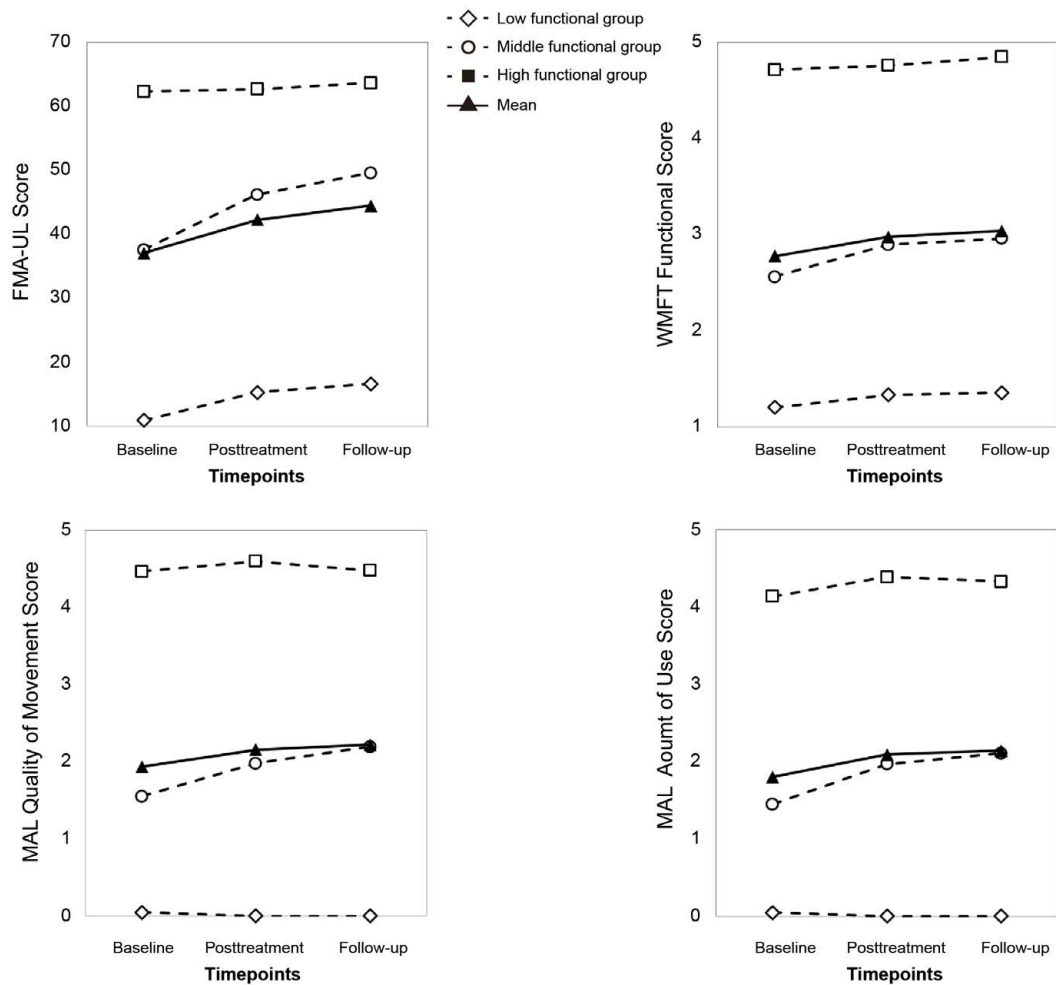
& p-values noted in this column are for overall test of whether the time course is different.

# p-values noted in this column are to test for change between baseline and posttreatment.

\* p Values noted in this column are to test for change between posttreatment and follow-up.

† p-values noted in this column are to test for change between baseline and follow-up.

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



**Figure 2:** 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.

| 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                                 |
|                            | <b>Question</b>  | <b>Extremely and quite unlikely</b> | <b>Slightly unlikely, likely and neither</b> | <b>Extremely and quite likely</b> |
| 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                                 |

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

chest pain stopped after the intervention. Also, one participant noted improvement in his aphasia. None of the participants reported any new complaints.

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. 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.

## Discussion

The objective of this study was to explore the efficacy and acceptability of Tai Chi used for upper limb rehabilitation post stroke. Tai Chi was adapted for twelve participants with different upper limb function and balance level. Participants with varied characteristics, including severe impaired upper limb, poor balance, shoulder pain, severe spasticity, and high medical comorbidity burden were capable of practicing their selected adapted Tai Chi movements. Eleven participants attended all 16 sessions and practiced more than recommended at home even in the follow-up month. Following the intervention, they showed significant improvements in the paretic arm motor function (FMA-UL, WMFT Functional Ability and Performance Time) and in the amount of paretic arm use in daily life (MAL, AOU scales). Initial shoulder pain of four participants decreased after the intervention. Moreover, the participants confirmed that they perceived Tai Chi to be useful. Overall, the findings from this exploratory study suggest that adapted Tai Chi is feasible and acceptable, and there are indications that it is effective in improving paretic upper limb function. To our knowledge, this is the first study to report the use of Tai Chi on upper limb rehabilitation after stroke.

Tai Chi was first adapted in this study to take into account the hemiparesis. For the participants with low upper limb function, upper limb movements were performed one side at a time, and only shoulder and elbow movements were emphasized. Sitting position was used for participants with poor balance. Consequently, participants with different upper limb function and balance level were able to practice Tai Chi. On the other hand, once their abilities permitted it, participants were encouraged to practice upper limb movements both together and to coordinate these with lower limb movements in standing positions. 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 [14-16]. Therefore, this study provided also an intervention using whole body rehabilitation for stroke survivors with sufficient balance. 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 [43]. However, Tai Chi can be performed for upper limb training even in patients with severe balance impairments.

Though previous studies suggested that movement practice was dramatically influenced by severity level in the paretic upper limb [44,45], the results of our study show that participants in stage 2 and 3 were able to practice their selected upper limb movements and receive the same practice duration and frequency as participants in stage 6 and better. Furthermore, the 8-week Tai Chi intervention was effective in improving motor function of their paretic upper limbs. Participants in stage 3 even gained large improvements in FMA-UL, WMFT functional scale and MAL scales. Though participants in stage 2 gained smaller improvements, their capability to perform multiple repetitions of Tai Chi movements is already a meaningful advancement. Therefore, these results suggest that even individuals with a Chedoke McMaster arm stage 2 and 3 could adopt a suitable and adapted restorative exercise program geared towards regaining function in the limb.

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. Their practice at home was in line with expectations in the first month and increased to an extent greater than expected in the second and follow-up month. Possible reasons for this may be that after the first month participants were more familiar with the movements, or they may have been more motivated to practice Tai Chi at home once they felt some improvements. Interestingly, participants in stage 2 and 3 practiced at home even more than participants in stage 6 and better. One reason may be that they were more motivated since their upper limb function was relatively low, or perhaps they may have felt more benefits 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 practicing Tai Chi, up to 67% of the participants in stage 2 and 3 indicated no difficulty practicing Tai Chi with their arms. All participants intended to continue practicing Tai Chi. These findings suggest that adapted Tai Chi is acceptable to chronic stroke patients with upper limb impairment.

There was a significant improvement in nearly all outcome measures over time except for WMFT grip and MAL QOM scale. The reason why the latter two measures did not significantly improve may be that they 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 ( $p=0.052$ ). 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. 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) [46], 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 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, MAL and 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 upper limb function. Given the exploratory nature of this study, we did not include a control group. However, since all participants in this study were in a chronic stage post stroke ( $\geq 8$  months after stroke onset), it is unlikely that the gains identified were only due to improvements from spontaneous recovery [47,48]. Moreover, 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 sec respectively) [49,50]. Therefore, we can be 95% confident that these statistical results were actual differences. Further studies are needed to provide more robust evidence of Tai Chi intervention.

While this study does not allow us to draw inferential statistical conclusions regarding subgroups of participants given the small sample size, 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 (Figure 2). For the low functional group, the reason may be that 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 amount was less than those two groups, which may contribute to reduced improvements given the lower number of repetitions. Nevertheless, they noticed improvements in their upper limb function, such as better flexibility of arm and hand, better handwriting, and driving. Therefore, the outcome measures may also 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.

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. Results showed that the three participants in low functional group had severe spasticity ( $MAS \geq 3$ ) and were able to follow Tai Chi sessions when given more time for relaxation. They did not receive their regular Botulinum toxin reinjections during the study, and they improved in the FMA-UL and WMFT functional scales. Furthermore, in an embedded study where an interview of eight participants was performed [51], most of them indicated that they felt that relaxation had helped improve their motor function and life activities. These data implied that muscle relaxation may play an important role in their motor recovery. The fact that the participants performed the adapted Tai Chi movements with multiple repetitions 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 exploratory study is that there was only one experiment group without control, though we used mixed effects model to analyze the repeated measures. There were no participants in stages 4 and 5 to enable the sample to have a full range of disability level. The interpretation of outcomes was limited by the small numbers in each subgroup. Furthermore, Botulinum toxin injections before intervention and co-rehabilitation may hinder the effects of Tai Chi. Therefore randomized controlled trials with strict inclusion criteria are required to provide more robust evidence of Tai Chi effectiveness on upper limb rehabilitation. 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 acceptable and effective for upper limb rehabilitation by stroke survivors with different impairment levels of paretic upper limb and balance. Participants demonstrated increased hemiparetic upper limb 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 upper limb rehabilitation approach. Further research with large-scale randomized trials is warranted.

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## Declaration of Conflicting Interests

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

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