Tai Chi Practice Reduces Movement Force Variability for Seniors

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Background. The purpose of this study was to examine whether Tai Chi practice can reduce the inconsistency of arm movement force output in older adults.

Methods. Twenty seniors took part in the 8-week-long exercise intervention program (12 in Tai Chi practice, \( M = 79.3 \) years, \( SD = 2.4 \); and 8 in a locomotor activity group, walking or jogging, \( M = 79.5 \) years, \( SD = 1.9 \)). Linear and curvilinear manual aiming movements were tested at the beginning (pretest), during 4th week (retest), and the end of the exercise program (post-test). The measure of vertical pressure on the surface of a tablet served as the dependent variable.

Results. The findings suggest that the Tai Chi participants significantly reduce more pressure variability than the participants in locomotor activity group after 8 weeks of practice. Additionally, seniors produced higher pressure variability in the curvilinear task than in the linear task.

Conclusions. Evidence from this study proposes that Tai Chi practice may serve as a better real world exercise for reducing force variability in older adults’ manual performance.
performed in our daily activities. In this study, linear and curvilinear manual tasks were used to assess the effects of Tai Chi or locomotor activity on the force control for arm/hand performance. Third, the arm movements used in the study are driven by the resultant force of horizontal and vertical planes. Because the downward pressure of arm movement on the contacting surface yields information regarding force fluctuation and magnitude during the movement (22), vertical pressure was the dependent measure to examine force control during arm movement execution.

After 8 weeks of Tai Chi practice, senior Tai Chi participants were hypothesized to better improve their consistency of force output during aiming arm movements than the participants who engaged in a form of locomotor activity (walking or jogging). Tai Chi's smooth, continuous, and well-coordinated arm and whole body movements may facilitate senior adults' integrating perceptual-motor information or reducing noise in their sensori-motor systems (e.g., effectively memorizing, planning, or executing movements), which may result in better control of force production in aiming arm movements.

**METHOD**

**Participants**

Twenty residents from a nursing home, ages 76 to 88 ($M = 78$ years, $SD = 2.3$), volunteered to take part in the study (Appendix, note 1). A survey conducted prior to the study indicated that all participants were independently ambulatory, right-handed, had normal or corrected to normal vision, and had no severe musculoskeletal or and neurophysiological disorders (e.g., arthritis, hand tremor, or Parkinson disease). They also had no prior experience with the manual tasks in the study. Tai Chi participants had minimal exposure or experience with Tai Chi at the beginning of the study. Most of the participants did not regularly engage in physical activities (e.g., exercising with a low frequency, short duration, and/or inconsistent schedule).

All participants passed the verbal part of the Mini-Mental State Examination (23), suggesting that the cognitive or mental capabilities of these individuals were normal (e.g., orientation, memory, and attention). These residents chose and participated in either one of the two exercise groups: Tai Chi ($n = 12$, $M = 79.3$, $SD = 2.4$; three males and nine females; weight $M = 70$ kg, $SD = 5.8$; height $M = 173$ cm, $SD = 3.7$) and locomotor activity (walking or jogging, $n = 8$, $M = 79.5$, $SD = 1.9$; two males and six females; weight $M = 68$ kg, $SD = 5.3$; height $M = 171$ cm, $SD = 3.8$) (Appendix, note 2). Informed consent was obtained that all participants were independently ambulatory, right-handed, had normal or corrected to normal vision, and had no severe musculoskeletal or and neurophysiological disorders (e.g., arthritis, hand tremor, or Parkinson disease). They also had no prior experience with the manual tasks in the study. Tai Chi participants had minimal exposure or experience with Tai Chi at the beginning of the study. Most of the participants did not regularly engage in physical activities (e.g., exercising with a low frequency, short duration, and/or inconsistent schedule).

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**Apparatus and Procedures**

A WACOM digitizer (UD-1218-R and a stylus pen: sampling rate at 205 Hz, 0.25 mm spatial accuracy, maximum 250 g/cm² vertical pressure) was used to measure arm movement performance. A portable personal computer (Sony PCG-717C) was connected to the digitizer displayed and recorded the arm movements (displacement, time, and downward pressure data).

The participants either engaged in Tai Chi practice or a low-intensity locomotor activity (walking or jogging) for 8 weeks: 3 times per week, 45 minutes per session, while under the supervision of trained personnel. Because the 24-form simplified Tai Chi practice (a modified form of Yang’s Tai Chi) is relatively easier to learn and control exercise duration and intensity than other styles (16,24), it was used in this study. According to the American College of Sports Medicine (ACSM) guidelines for exercise testing and prescription (25), a low-intensity exercise refers to a physical activity that produces a less than 60% of maximum heart rate (HR) for its participants. Thus, the HR was controlled at an average level of 100 beats/min for all the activities involved. Manual movement tests were conducted before the intervention (pretesting), at week 4 of the practice/exercise (retest), and at the end of the practice/exercise (post-testing). Each participant was tested individually and given standardized instructions for the tests.

Each participant sat in front of the digitizer placed on a table-top. With the right hand, each participant held a stylus pen in a writing style and performed the linear and curvilinear tasks in a counterbalanced order. After the “start” signal was given, the participant moved a hand-held stylus from the starting position to the target as rapidly and as accurately as possible, and with minimum and consistent vertical downward pressure (Appendix, note 3). In the linear task, each participant moved the pen directly to the target (a forward arm motion in the midline of the body). In the curvilinear aiming task, each participant moved the pen in a curved line, passing the stylus through a circle that was located midway between the starting position and the target (8 cm off the straight line), and then stopped inside the circle of the target.

To prevent any body movements, each participant was required to keep the chest against the table during the arm movements. Only the successful trials (the hand-held stylus moved into the circle of the target) were analyzed to standardize the motion performed, and reduce the movement intertrial variability for each participant (Appendix, note 4). The distance between the target and the starting position was 20 cm (about 60% of the arm length), and the diameter of the target/home circle was 2 cm. Each participant had a total of five to seven practice trials (to fully understand the tasks), followed by 20 data trials for each task (the means of data trials were used for the analyses). Figure 1 shows the linear and curvilinear manual tasks.

**Data Analyses**

The raw data were filtered using a Butterworth digital filter with a cutoff frequency of 8 Hz. Movement position ($x$, $y$ axes), time, and pressure data ($z$ axis, downward direction) were then reduced for the analyses (see Appendix, note 1). The computer software registered movement “onset” when the velocity exceeded 4 mm/s. The movement “offset” was marked as the arm movement stopped inside the target (the velocity at the last sampling point declined below 4 mm/s). Movement duration or time (MT) was the time from the “onset” to the “offset” of the arm movement.

As soon as the stylus touched the digitizer, the arm movement produced a continuous downward pressure on the surface of the digitizer until the stylus departed from the digitizer. A standard deviation (SD) of 20 data points of pressure between the “onset” and “offset” of movement (movement duration or MT) was used to measure the overall variability in arm movement force output. For each trial, 20 data points of pressure were sampled in terms of equal MT among data points (Appendix, note 5). Then for...
each trial a SD was computed for these 20 data points. Because the MTs were slightly varied among the participants, in any given trial the pressure variability was standardized: the SD of 20 data points/MT. The average standardized SD for 20 data trials was used as a dependent measure for overall pressure variability. A smaller standardized SD represented less variability in pressure during the execution of arm movement.

An analysis of variance (ANOVA) with repeated measures was used to analyze the data. The independent variables were the type of exercise (Tai Chi vs locomotor activity) and the task (linear vs curvilinear task). The repeated-measures factor was the testing session (pretest, retest, and post-test). The dependent measure was overall variability in arm movement pressure. No examination was conducted for the gender effect because no gender-associated differences have been identified in senior adults’ arm movements (3).

RESULTS

Means and SDs for overall variability in movement pressure (g/cm²) between Tai Chi and locomotor activity among the tasks across three test sessions are displayed in Figure 2. There were no significant three-way interactions (exercise type by task by test session), two-way interactions, nor main effects of exercise type and test session. However, the effect of task was significant, $F(1,18) = 34.43, p < .001$. The participants had a higher pressure variability in the curvilinear task than in the linear task. Furthermore, within the curvilinear arm movement task, the interaction of Exercise Type by Test Session, $F(2,17) = 7.79, p < .01$; the main effects of exercise type, $F(1,18) = 6.32, p < .05$; and test session, $F(2,17) = 25.62, p < .001$, were significant. The results suggest that in the curvilinear arm movement task (the top panel, Figure 2), Tai Chi participants demonstrated considerably more reduced variability in movement pressure than their counterparts in the locomotor activity group. Because the linear task reflected a trend in training effect, the data were still reported even though no statistical significance was found (the bottom panel, Figure 2).

Figure 3 demonstrates four characteristic pressure profiles of the curvilinear arm movements (Appendix, note 6). These samples indicate that after Tai Chi practice, the participant executed the curvilinear arm movement with increased consistency in controlling force output, whereas the participant in the locomotor activity did not substantially reduce the inconsistency. These data support the prediction that Tai Chi practice is a better form...
of exercise for stabilizing force outcome during manual aiming movements.

DISCUSSION

Research on aiming arm movement control is primarily interested in the processes that underlie force production as well as in the factors that cause variability in force production (9,10). Studies have reported that in addition to inconsistent force production in senior adults' motor performance, aging is associated with slower, more variant, and less smooth motor responses (3–5,7). Cognitive deficits or noise in senior adults' motor systems may contribute to, in part, their decline in motor performance (11–13). At issue in this study was whether Tai Chi practice could enhance its participants' sensorimotor integration or reduce cognitive deficiency by better preparing and coordinating the arm and total body movements.

The results of this study suggest that relative to locomotor

activities, Tai Chi is a better form of exercise for improving the consistency in senior adults' force output during the curvilinear arm performance (Figure 2, the top panel; Figure 3). One possible explanation for this finding would be that in comparison with exercise of walking or jogging, Tai Chi involves more total body exercise as well as more brisk arm movement training, leading to a better practice effect. For instance, a Tai Chi routine includes a variety of continuous curvilinear arm movements, as well as the combination of linear and curvilinear arm movements. This may explain why after 8 weeks of exercise, Tai Chi participants considerably decreased force variability in the curvilinear manual movement to a greater degree than the senior individuals who were engaged in a locomotor activity (Figures 2 and 3). These data demonstrate the benefits of an alternative exercise (e.g., Tai Chi) for reducing seniors' variability in force output that were not previously reported in the studies of aging and physical activity.
Furthermore, from a perceptual motor control perspective, several characteristics of Tai Chi may explain its beneficial effects on force control during manual aiming movements. For example, Tai Chi’s fundamental characteristics such as its demand for mental concentration over its slow, smooth, self-paced, and coordinated whole body movements, along with its requirement for remembering and understanding body orientations, movement patterns, and the sequence of the movement routine (16), provide the Tai Chi participants a unique exercise in utilizing sensory information for movement control.

Particularly, Tai Chi practice focuses on learning and practicing the body motions in a progressive sequence. A Tai Chi performer has to understand and remember all movement components in order to complete the whole routine. In addition, the movements are performed slowly, smoothly, and in a self-controlled rhythm. These movement characteristics direct a performer’s attention to the sensory information that the performer can integrate into the controlled arm and total body movements. Because the Tai Chi movements are slow and the performers focus on the performance, the participants, especially the senior adults, would have adequate time to process sensorimotor information for body movements. Alternatively, as a function of Tai Chi practice, the senior participants might reduce cognitive deficits or noise by better response preparation that was reflected in improved force control in the manual movement tasks. Thus, strengthening senior adults’ use of sensory feedback may be an essential factor for force control.

However, all participants had higher force variability in the curvilinear task than in the linear task (Figure 2). The curvilinear task was more complex than the linear task (controlling movement path or changing movement direction during the execution), leading to a higher force variability (26). The results suggest that manual movements involving higher task demands or constraints may decrease the performance level of seniors. To maintain relatively stable motor functions or performance, reducing the degree of task complexity can be a useful strategy for older adults.

In short, the findings from this study suggest that Tai Chi practice may serve as an alternative physical activity for improving senior adults’ force control in aiming arm movements. Tai Chi’s deep concentration could facilitate perceptual motor integration (movement preparation and execution), and lead to consistent force production for the curvilinear arm movements. Practically and theoretically, extensive Tai Chi practice may improve the quality of life of senior adults as well as enhance their manual movement functions.

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REFERENCES


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Appendix

1. Initially 68 seniors signed up for this research project. Data were excluded for the residents who did not pass the Mini-Mental State Examination (14 individuals, 20%) and who missed 20% of the Tai Chi practice or locomotor activity sessions (additional 16 individuals, 24%). Kinematic data of curvilinear manual tasks and the results of balance testing for these 38 participants were reported in Yan (18). In addition, participants who had missing data points in vertical pressure of either linear or curvilinear manual tasks were not included in the next part of research (additional 18 individuals, 26%). Therefore, only 20 seniors
remained in the present study, which examined the effects of Tai Chi on kinetic characteristics of linear and curvilinear manual tasks.

2. Considering the age of the participants (from 76 to 88 years of age), their exercise forms (80% of the residents irregularly participated in walking or jogging), and their preference of activity intervention, to facilitate residents’ active engagement in the study and maintain a relatively low drop-out rate, each resident was allowed to select his/her own activity in this study (either Tai Chi or a locomotor activity).

3. The interval between the “start” signal and the “onset” of the arm movement (RT) ranged from 280 to 350 ms. After five to seven practice trials, most seniors understood the task requirements. There were not significant differences in the error rates between groups: Tai Chi, linear task, $M = 18\%$, curvilinear task, $M = 23\%$, Locomotor activity, linear task, $M = 16\%$, curvilinear task, $M = 22\%$.

4. Two major aspects of difference were observed between the unsuccessful (missing the target) and successful (hitting the target) trials in the manual movements. Besides missing the target, typically the unsuccessful trials were inconsistent and awkward, resulting in a greater variability in the movement paths than the successful trials. To compare similar movement characteristics between Tai Chi and locomotor activity, only the successful trials were analyzed.

5. MT ranges: from 500 to 800 ms for the linear task and from 1200 to 1800 ms for the curvilinear task. Certainly more data points of pressure could better reflect the differences in pressure variability. Because the interval among data points was very short: 60 to 100 ms by using 20 data points, the use of the $SD$ of 20 data points could be considered reasonably accurate in capturing the variability of pressure during arm movement execution.

6. The trials that had the closest values to the group means of pressure and MT were selected as the typical trials.