Effects of 24 weeks of Tai Chi Exercise on Postural Control among Elderly Women

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This study examined the effects of 24 weeks of Tai Chi Quan on the postural control of elderly women. A total of 43 women aged 55–68 years participated in the study. A Tai Chi group (n = 22) underwent an organized Tai Chi exercise, whereas the control group (n = 21) maintained a habitual, no-regular-exercise lifestyle. A Good Balance tester (Metitur, Finland) was used to measure the time, paths and velocity of the center of pressure (COP) of subjects during stance while shifting COP to targeted positions shown on a monitor. After 24 weeks, the Tai Chi group showed significantly shorter total (18.6%, \( p = 0.005 \)), mediolateral (21.9%, \( p = 0.002 \)) and anteroposterior (18.3%, \( p = 0.002 \)) COP sway paths than the control group. The results indicate that 24 weeks of the Tai Chi exercise improved the efficiency of postural control for elderly women.
INTRODUCTION

Regular Tai Chi Quan exercise (or Tai Chi) improves the postural control and balance of elderly people. Most studies measured the duration at which participants can maintain balance in a single stance with eyes open or closed (Li, Xu, & Hong, 2008) or in tandem stance with eyes open (Barbat-Artigas, Filion, Dupontgand, Karelis, & Aubertin-Leheudre, 2011). Other Tai Chi studies measured the sway of the center of pressure (COP) when participants were instructed to stand as still as possible on a fixed force platform (Chen, Zhou, & Cartwright, 2011; Tsang & Hui-Chan, 2006). The sway was also measured when participants stood on a sway-referenced or perturbed force platform (Tsang, Wong, Fu, & Hui-Chan, 2004; Tsang & Hui-Chan, 2005). These studies simulated the balance control of older people in more critical situations, such as when their stances are supported by a single leg without vision or when their foot strikes a moveable item during walking. All the above studies showed favorable results for the Tai Chi practitioners as compared with the control participants.

Older people are required to control their balance in other critical situations, which include leaning the body to a far, targeted position to perform specific functional activities during stance. Such activities are often fundamental but have become challenging for these people (Mao, Hong, & Li, 2006). To simulate this situation, the sway of COP was measured when participants were asked to stand on a force platform and shift their body to spatial limits without losing balance (Gyllensten, Hui-Chan, & Tsang, 2010; Tsang & Hui-Chan, 2003; Tsang et al., 2004; Wong, Lin, Chou, Tang, & Wong, 2001). Results showed that Tai Chi practitioners could lean further without losing stability than the control participants. The maximum leaning distance is the critical indicator that shows the spatial range at which the participants can lean their bodies while maintaining balance.

Postural control involves how efficiently people can lean the body into far, targeted positions while maintaining balance. The efficiency of dynamic postural control can be evaluated by measuring the sway of the COP of participants who are instructed to shift their COP to far, targeted positions during stance without losing balance (Wong et al., 2001). The lower values of sway paths are associated with higher efficiency posture control during the endeavor to shift the body weight, and vice versa. The sway velocity of COP was another indicator to assess balance and postural control ability in the previous studies. Pyykko, Jantti, and Aalto (1990) used a strain force platform to study the postural control of different aged people under static conditions. When elderly participants, aged 85 years or over stood with their eyes open on a firm surface, their sway velocity was nearly three times higher than that of the control participants aged 50 to 60 years old. With the use of the Good
Balance system, Fernie, Gryfe, Holliday, and Llewellyn (1982) found that the average velocity of COP sway was significantly greater for those who fell one or more times in a year than those who did not. In a dynamic balance test, Shih (1997) used a force platform (AMTI, USA) to measure the velocity of the COP sway in the anterior and posterior directions in healthy adults who underwent a 16-week Tai Chi intervention; the velocity of the COP sway in the anteroposterior direction in the post-test was decreased relative to that in the pre-test. The above studies showed that lower values of velocity are indicative of better postural control, which is associated with the reduced risk of falls, younger age, or Tai Chi exercise. The higher sway velocity in the balance test can be attributed to the higher COP sway frequency that resulted in a longer duration and longer sway path; high sway velocity is also associated with lower balance stability. Hence, duration, sway path, and sway velocity of COP movement were used in the present study.

We designed this study to investigate whether or not 24 weeks of organized Tai Chi exercise can improve the efficiency of postural control in elderly women. The force plate system called Good Balance (Metitur, Finland) is a useful tool for measuring the efficiency of postural control under dynamic conditions because the sway of the COP, in terms of time, path and velocity of sway, can be measured when participants standing on the force platform are required to trace the COP target positions shown in the computer monitor (http://www.metitur.com). We hypothesized that the elderly healthy women who engaged in a 24-week organized Tai Chi exercise would show lower values of duration and total, mediolateral and anterioposterior sway paths and sway velocities of COP movement in the balanced stance while moving the COP to reach specific target positions compared with their sedentary counterparts. The results of this study are expected to enhance the existing knowledge on the beneficial effects of Tai Chi on postural control and fall prevention in the elderly.

METHODS

Participants

Community-dwelling women ranging in age from 55 to 68 years old in a metropolis in China were recruited to participate in the study. Recruitment was performed through the Metropolis Senior Citizen Sports and Recreation Association. Qualified participants should have no previous regular sports and exercise experience and have no Tai Chi experience. They should have no history of falls, neurological diseases that impair mobility, hypertension, cardiomyopathy, dyskinesia, and Parkinson’s symptoms. A total of 52 women were finally selected. The participants were randomly assigned to the Tai Chi (26) and control groups (26). Among them, 22 in the Tai Chi group and 21 in the control group completed the 24-week intervention and accepted the final balance test. An informed consent form was signed by each participant prior
to participation. This study was approved by the local medical ethics committee. Before the program commenced, all the participants underwent a balance baseline test.

Exercise Intervention
The participants in the Tai Chi group underwent 24-week programmed Tai Chi training supervised by a qualified Tai Chi instructor. The training was arranged for at least four sessions per week, with each session lasting 60 min. In the first six weeks, the participants were taught the 24-form Tai Chi. Each session included a warm-up for 10 min, learning new forms for 20 min, reviewing the learned forms for 20 min, and cooling down for 10 min. In the subsequent 18 weeks, the participants were guided by an instructor in each session to perform a 5 min warm-up, 50 min practice and refinement, and 5 min cool-down. The participants performed a collective exercise in a fixed location. The control group maintained their previous lifestyle. The researchers communicated with the control group twice weekly to confirm that they are not participating in any programmed exercise. They were assured that they would be taught Tai Chi after the intervention period.

Measurement
Measurement was conducted in a Good Balance system (Metitur, Finland) that comprises a portable triangular force platform (800 mm × 800 mm × 800 mm) with strain-gauge transducers connected to a three-channel direct-current amplifier and a 12-byte analog-to-digital converter connected to a computer. The sampling frequency for each channel was 50 Hz. After all measurement points were read, the mediolateral (x) and anteroposterior (y) coordinates of the COP were calculated on basis of the vertical force applied to the transducers by the system software. The error in the calculated x and y coordinates of the COP is less than 1.0 mm when the mass of the participant is 40 kg or above (http://www.metitur.com). The system has been used in previous aging studies to measure the sway of COP of older people (Era et al., 1996; Pajala et al., 2004, 2008; Viljanen et al., 2009).

All measurements were performed in the morning. The participants were requested not to engage in exercise on the day before measurement. Before the measurement, the participants were given two opportunities to familiarize with the Good Balance system and the test procedure. The participants then underwent the same measurement before and after the 24-week intervention.

A measurement for each participant lasted for 15 minutes. Before the measurement, the participants were given 20 min to rest. During the measurement, if the participants felt fatigued, then they were allowed to rest for a few
minutes before continuing. The measurements were conducted at the Biomechanics Laboratory. A maximum of four participants who underwent the experiment were evaluated for each session. Two experienced technicians conducted the experiment: one technician was responsible for operating the Good Balance system, and the other one assisted the participants to undergo the test correctly.

Before the measurement commenced, the participants were asked to stand with bare feet parallel on both sides of the central line of the force platform. The distance between the feet was as wide as the shoulder (Figure 1, upper left). The participants were asked to keep their arms down at their sides with eyes open and to distribute their body weight evenly on both legs. When the computer showed that the bilateral distribution of body weight was 50%, this result indicated that the standing position was correct, and therefore the sway measurement can be started. However, if the load was unevenly distributed on both sides, then the standing position was adjusted until even distribution was achieved (Pajala et al., 2004, 2008; Viljanen et al., 2009).

During the measurement, the participants were asked to watch the computer monitor of the system that was set in front at a constant distance from the force platform. The monitor of the computer was installed in such a way that its center was level with the participants’ eyes. As shown in Figure 1 (bottom left), four squares in the monitor screen display the origin (Position 1), which was the position of COP when the participants settled down on the

**FIGURE 1** (1) The upper left figure shows the stance on triangle force platform. (2) The bottom left figure is a diagram demonstrating the COP positions in the computer monitor. The square No. 1 demonstrates the origin position, the squares No. 2, 3 and 4 demonstrate the Position 2 (front left position in the monitor), Position 3 (front position in the monitor) and Position 4 (front right position in the monitor), respectively. The arrows show the movement order of COP. (3) The right figure is the path of COP in a complete dynamic balance measurement.
force platform, and the other three target positions, namely, front left (Position 2), front (Position 3), and front right (Position 4). Locations of the target positions on the monitor were the same for all participants. In a complete sway measurement, the participants were asked to move their COP from the origin to the target positions in the order of 2, 3, and 4. Before moving to the next target position, the COP must return to the origin. After reaching Position 4, the COP must also return to the origin. The squares were highlighted one by one in this order for the participants to follow. The participants were instructed to move the COP in the shortest path and time possible and bring the COP to each position as accurately as possible. If the participants lost their balance, then they were asked to repeat the procedure from the beginning. Figure 1 (right) also shows the movement route of the COP of one participant in the complete experiment. The output variables included the total time spent to complete the test, total length of COP path and its components in mediolateral (x) and anteroposterior (y) directions, and the average COP velocity and its components in mediolateral (x) and anteroposterior (y) directions. The participants were required to complete the test for three times, and the mean values of the results were analyzed.

Statistics

Data were analyzed using SPSS 17.0. All variables were presented as mean ± standard deviation. At the beginning of the experiment, an independent t-test was employed to compare the difference of the variables between groups at baseline. After the experiment, ANOVA with a mixed design was used to compare variables within and among the groups. If any significant effect was detected, then a within-group difference was compared using the paired t-test. The difference between groups after intervention was compared using an independent t-test. The significance level was set at 0.05.

RESULTS

Among the 52 participants, 22 in the Tai Chi group and 21 in the control group completed the 24-week intervention and accepted the final balance test. The dropouts were attributed to illness, family reasons, and loss of interest. The attrition rate was 17.3%. Participant compliance to the Tai Chi intervention was assessed by using the number of attendants divided by the number of sessions provided. The mean participation rate was 92%, with a range of 80% to 100%. The research result is considered effective. The dropouts did not significantly affect any of the outcomes or demographic measures at the baseline measurement in both groups. No significant differences in age, height, and weight were found between the two groups (Table 1).
The pre- and post-intervention balance data of the participants who completed the program were compared. Table 2 shows all variables of the pre- and post-intervention measures. No significant differences in all variables were found between the Tai Chi and control groups in the baseline measures.

The two-way ANOVA with repeated measures design revealed that there were no significant differences on the main effects of group and time, and their interaction on the variables of sway velocity and duration. However, significant differences were found on the main effect of the group on the total \((F(1,172) = 5.620, p = 0.020)\), mediolateral \((F(1,172) = 7.471, p = 0.008)\) and anteroposterior \((F(1,172) = 6.479, p = 0.013)\) COP paths. The further independent t-test showed that after intervention, the Tai Chi group showed a significantly shorter total \((18.6\%, p = 0.005)\), mediolateral \((21.9\%, p = 0.002)\) and anteroposterior \((18.3\%, p = 0.002)\) COP sway paths than did the control group (Table 2).

The paired t-tests were used to compare the changes in measures within groups. Table 2 shows that Tai Chi exercises shortened the lengths of the COP total path and its components in the mediolateral \((x)\) and anteroposterior \((y)\) directions by \(15.6\% (p = 0.009)\), \(14.9\% (p = 0.034)\), and \(16.7\% (p = 0.004)\), respectively, against the baseline results. No significant difference from the baseline was found in other post-intervention measures for both groups.

### DISCUSSION

The main findings of this study were that 24 weeks of Tai Chi training induced shorter total, mediolateral and anteroposterior sway paths of the COP of the participants during the endeavor to shift their weight to special, targeted positions as stably as possible and in as short a time as possible without losing balance. The control group didn’t change the sway paths of COP after the intervention period, indicating no learning effects were induced with the methods. The ability to control the intentional body lean in different directions is important for older people to perform various functional activities, which are often encountered daily (Tsang & Hui-Chan, 2003). Thus, determining whether or not Tai Chi exercise improves the dynamic balance control ability of older people is important. Tsang and Hui-Chan (2003) measured the spatial limits by which participants could shift their body weight without losing...
## TABLE 2 Variables of Dynamic Balance Measures and Within- and Between-Groups Comparison (Time in seconds, Length in mm, Velocity in mm/s)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Tai Chi group</th>
<th></th>
<th>Control group</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
<td>Post-test</td>
<td>$p_a$</td>
<td>$p_b$</td>
<td>$p_c$</td>
<td>$p_d$</td>
<td></td>
</tr>
<tr>
<td>$T$</td>
<td>17.45 ± 4.19</td>
<td>16.78 ± 4.58</td>
<td>17.45 ± 4.64</td>
<td>17.46 ± 3.65</td>
<td>0.615</td>
<td>0.999</td>
<td>0.994</td>
<td>0.596</td>
<td></td>
</tr>
<tr>
<td>$L$</td>
<td>1256.9 ± 289.85</td>
<td>1061.3 ± 163.51</td>
<td>1261.1 ± 329.00</td>
<td>1303.4 ± 342.87</td>
<td>0.009</td>
<td>0.963</td>
<td>0.671</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>$L_x$</td>
<td>767.06 ± 205.42</td>
<td>653.01 ± 27.78</td>
<td>814.23 ± 59.03</td>
<td>836.54 ± 231.46</td>
<td>0.034</td>
<td>0.524</td>
<td>0.775</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>$L_y$</td>
<td>830.82 ± 187.71</td>
<td>692.45 ± 94.57</td>
<td>832.15 ± 196.83</td>
<td>847.05 ± 188.10</td>
<td>0.004</td>
<td>0.981</td>
<td>0.793</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>$V$</td>
<td>75.23 ± 23.80</td>
<td>67.53 ± 20.01</td>
<td>74.84 ± 21.18</td>
<td>75.89 ± 17.96</td>
<td>0.281</td>
<td>0.640</td>
<td>0.855</td>
<td>0.157</td>
<td></td>
</tr>
<tr>
<td>$V_x$</td>
<td>45.65 ± 14.21</td>
<td>41.93 ± 14.41</td>
<td>47.63 ± 15.44</td>
<td>48.80 ± 12.69</td>
<td>0.426</td>
<td>0.891</td>
<td>0.778</td>
<td>0.105</td>
<td></td>
</tr>
<tr>
<td>$V_y$</td>
<td>50.00 ± 17.44</td>
<td>43.77 ± 11.67</td>
<td>49.85 ± 14.73</td>
<td>49.43 ± 9.72</td>
<td>0.196</td>
<td>0.512</td>
<td>0.908</td>
<td>0.091</td>
<td></td>
</tr>
</tbody>
</table>

$T$—Total time of the COP shift.

$L$—Length of total path of the COP.

$L_x$—Component of $L$ in the mediolateral ($x$) direction.

$L_y$—Component of $L$ in the anteroposterior ($y$) direction.

$V$—Mean of total velocity of COP.

$V_x$—Component of $V$ in the mediolateral ($x$) direction.

$V_y$—Component of $V$ in the anteroposterior ($y$) direction.

$p_a$—Comparison for Tai Chi group before and after intervention.

$p_b$—Comparison between Tai Chi and control group before intervention.

$p_c$—Comparison for control group before and after intervention.

$p_d$—Comparison between Tai Chi and the control group after intervention.
balance and reported that eight weeks of intensive Tai Chi training can improve balance control in elderly people. Using the same method, Tsang et al. (2004) measured the spatial limits by which participants could shift their body weight without losing balance and reported that older Tai Chi practitioners, with a mean of 8.4 years of Tai Chi experience, have better balance control than their sedentary counterparts. Unlike previous studies, the present study investigated different scopes (e.g., efficiency) of balance and postural control. For this purpose, the sway paths of the COP of the participants were measured when they shifted the COP to targeted positions. The result showed that after 24 weeks Tai Chi training, the participants could control the body posture to complete a targeted weight shift in a more efficient way.

To the best of our knowledge, the effects of Tai Chi on the efficiency of postural control have not been well documented. In this study, the participants were instructed to move the COP between three target positions and the initial position, the origin, in a specific order in the shortest path and time possible. The primary objective was to determine the sway path, whereas the secondary objective was to determine the time and velocity of sway. Therefore, good postural control ability is associated with shorter paths of the COP. If the participants moved the COP extremely fast, then the COP will deviate from the optimal track between the origin and the target positions, such that both the length of the COP path and the time spent would increase. If the participants possess good postural control ability, then they could move the COP to the target positions swiftly, thereby reducing the COP velocity. In this study, the Tai Chi group had shorter COP paths compared with the baseline and control group after intervention. These results indicate the beneficial effects of Tai Chi on postural control ability, such that the target COP position could be more efficiently achieved. After 24 weeks intervention, Tai Chi group shortened the time and total, mediolateral and anteroposterior velocities of sway of the COP, and these values were also smaller than that of the control group after the 24 week period; however, the differences were not significant. This result didn’t prove the hypothesis, which might be attributed to the short training period, and so warranted future study in a longer intervention period.

The positive effects of Tai Chi training on dynamic balance and postural control can be attributed to the kinematics and dynamics of Tai Chi movements. During Tai Chi exercise, practitioners are requested to shift their bodies in different directions, including forward, backward, sideways, up and down, fixed, and turning. The movements are performed in single stance, double stance, and changing between the two stances (Mao, Hong, and Li, 2006). These movement patterns are similar to the test condition in the present study, in which the participants are requested to shift their body weight in different directions. In addition, all Tai Chi movements are performed in slow, smooth patterns that demand the high control of plantar exertion. Moreover, in Tai Chi movements, practitioners are asked to trace a target visually by using the hand and then translate the body in the
direction of the target moves. These movements are similar to the test conditions in the present study, which require visual feedback and coordination of multiple body segments. Law and Li (2014) studied the ‘repulse monkey’ and ‘wave hand in cloud’ movements. In the repulse monkey stance, vision is focused on the fingers of the arm that is moved backward in a curved line, while the leg of the same side takes a backward step, accompanied by trunk rotation to the same side. In the wave hand in cloud, vision is focused on the fingers of the arm that is laterally moved in front of the eyes from one side to another, while the leg of the same side takes one step in the same direction as the arm movement. The results of a temporal and kinematics study showed that these two movements are gentle and fluid and thus possess unique biomechanical features that enable special training for postural control capacity. Xu, Li, and Hong (2003) studied typical Tai Chi movements, namely, brush knee and twist steps, which are symmetrically performed on the left and right sides. The practitioner’s vision is focused on the fingers of the arm that is moved forward at the level of the ear, while the leg of the opposite side takes a forward step accompanied by trunk and head rotation. A kinematics and electromyography study showed that continuous shifting of the center of gravity and alteration of muscle loading, a wide range of the motion of the joint, as well as well-controlled muscle coordination would produce particular benefits for postural control. In summary, the repeated practice of Tai Chi enhances the ability for visual feedback and movement coordination, which are essential for postural control and balance. Thus, Tai Chi, as a favored exercise by the elderly, may reduce the risk of falling and is strongly recommended for the elderly.

To understand the dynamic characteristics of Tai Chi movements, Mao, Li, and Hong (2006a) studied the plantar exertion in five typical Tai Chi movements, namely, the brush knee and twist steps, step back to repulse monkey, wave hand in cloud, kick heel to right/left, and grasping the bird’s tail. These movements represent five stepping directions, namely, stepping forward, backward, sideways, up and down, fixed, and turning movements. Plantar exertion in all single stance movements of a set of 42 movements of Tai Chi has also been studied (Mao, Li, and Hong, 2006b). Results showed that the loading of the first metatarsal head and the great toe is significantly greater than that of other regions. The COP displacement in both anterioposterior and mediolateral directions was larger than that in normal walking. Thus, we speculated that the plantar pressure characteristics in Tai Chi exercise may intensify the plantar cutaneous tactile sensory input from the first metatarsal head and great toe areas, increase the muscle strength of the lower extremities, and subsequently improve balance control.

Another difference of the present study from the previous ones lies in the intervention period. Li, Xu, and Hong (2008) studied the effects of 16 weeks of Tai Chi intervention on the postural stability and proprioception
of the knee and ankle in older people and reported that the improvement in postural stability without vision and proprioception of the ankle by Tai Chi intervention could not reach a significant level. In another study, Li, Xu, and Hong (2009) examined the changes in muscle strength, endurance, and reaction of lower extremities after 16 weeks of Tai Chi intervention and reported that the strength and reaction time of the knee extensors, strength of ankle muscles, and the endurance of knee muscles did not reach the level produced by long-term Tai Chi exercise. Both studies indicated that the insufficient improvement might be due to the limited training period. They suggested that future studies might verify these results with an extended period for TC intervention. Based on these two well-established studies, the present work selected 24 weeks as the training period; most of the community-based Tai Chi training programs are normally designed to last for 24 weeks.

CONCLUSION

A 24-week Tai Chi exercise period reduced the total, mediolateral, and anteroposterior sway path of the COP during standing on a force platform to move the COP to targeted positions without losing stability. These results confirmed that 24 weeks of Tai Chi intervention improved the efficiency of older women in body control in dynamic situations. This improvement could help older people to control their posture and balance in leaning their body towards specific targets. Such tasks are often encountered in their daily lives.

DISCLOSURE STATEMENT

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