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Tai Chi and Its Effects on Dynamic Postural Control in the Initiation of Gait by Older People

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Abstract. [Purpose] This study examined the changes in the translation of the center of pressure (COP) when older adults initiated gait before and after Tai Chi (TC) training. [Subjects] Twenty older adults, ranging in age from 65 to 83 years, participated in a 16-week TC training program. [Methods] Before and after the TC training the subjects were asked to perform gait initiation (GI). The subjects exercised with Sun-style TC, which incorporates elements that emphasize continuous flowing movement, balance control, endurance, strength, concentration and awareness of the environment, three times per week over a 16-week period. The differences in COP excursion in the antero-posterior (A-P) and mediolateral (M-L) directions between pre- and post-training were analyzed using the data collected from two force plates. [Results] The COP displacement in the A-P and M-L directions after TC training was increased significantly compared to that observed pre-training. [Conclusion] The 16-week practice of TC improved the ability of participants to generate momentum via a greater COP shift in the A-P and M-L directions in the initiation of gait as well as their ability to maintain balance and lateral stability. TC training may be effective for prevention of falls among the healthy elderly.
Key words: Rehabilitation, Tai Chi, Aging

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INTRODUCTION

Falling is the leading cause of injury and death among the elderly and the most common cause of nonfatal injuries and hospital admissions for trauma[1)]. More than 18,000 of the elderly died from unintentional fall injuries in the United States in 2007 and the death rates from falls by the elderly have increased sharply over the past decade[1,2)]. Furthermore, falls by the elderly have created serious economic pressure on health systems as the direct medical costs of falls for people aged 65 and older in 2001 exceeded $19 billion, $179 million for fatal falls and $19 billion for non-fatal fall injuries[3)].

The most common type of fall-related fracture is fracture of the hip[4)]. In the United States, there were approximately 316,000 hospital admissions for hip fractures in the elderly in 2006. It is estimated that the number of hip fractures will increase to 500,000 by 2040[4)]. The medical cost of hospitalization for hip fracture is approximately $18,000, which represents 44% of the total direct medical costs for hip fractures[5)]. Overall, fall-related injuries and the associated health care costs present a serious public health problem. Therefore, minimizing falls and fall-related injuries among the elderly is warranted.

Recently, there has been increased interest in providing intervention for fall prevention programs to reduce falls, and fall-related injuries, and to achieve greater levels of independence among older adults. However, their effectiveness as a means of fall prevention for older adults is controversial[6)]. Several studies have reported that exercise programs help older adults reduce their risk of falling[7–9)], improve muscle strength[10–12)], and enhance gait and postural stability[13,14)], but other studies have reported no effect on the prevention of falls[15–17)].

Tai Chi (TC) is a traditional Chinese form of exercise that is derived from an ancient Chinese martial art and has been practiced for centuries for the promotion of human health in Asian countries[18)]. TC is different from routine strengthening and stretching, and presents a class of exercises that consist of a series of slow, rhythmic, continuous graceful movements, with small to large expressions of motion, unilateral to bilateral shifts in body weight, rotation of the trunk, head and upper and lower extremities in combination with deep diaphragmatic breathing and relaxation. Therefore, it emphasizes the smooth integration of trunk rotation, coordination and a gradual narrowing of the lower extremities. It is classified as moderate exercise and its intensity is approximately equivalent to walking at a speed of 6 km/h[19)].

Recent studies have demonstrated that participation in TC may be effective for reducing falls and fall-related injuries as it improves balance control[20–22], postural stability[23], muscle strength and flexibility[24,25], blood pressure[26] and cardiovascular function[27] of the elderly. Although these findings demonstrate the benefits of TC as an exercise program, few studies have examined the effects of a TC exercise program on motor coordination and postural control when initiating gait from the position of quiet stance. Moreover, despite the fact that TC may improve balance and reduce falls among the elderly, a limited number of studies have examined the potential underlying mechanisms for the improved balance and postural stability of the elderly after TC practice.

There are two reasons why gait initiation (GI) can be used as an investigative tool to determine the mechanisms of the changes in the gait pattern after TC training. First, GI is a transitional movement between static balance in a quiet stance and the start of steady-state walking[28,29]. Therefore, GI might be a functionally appropriate task for differentiating unstable elderly from healthy elderly and young adults, because falls in the elderly often occur during movement transitions, such as the initiation and termination of gait and changing direction[30,31]. Second, the center of pressure (COP) in the sagittal plane, or the point where the ground reaction force vector originates, is controlled by the interaction of the antagonist muscles at the ankle[32–34]. Since GI involves a stereotypical pattern of muscle activity, problems or subtle intervention-related changes in GI can be identified easily.

One possible mechanistic approach for investigating the effects of TC training during ambulation is to examine the displacement of COP because the changes in the translation of COP reflect the response of the central nervous system to movement in the whole body center of mass (COM)[35]. Therefore, COP is commonly used as an indicator of balance and postural control[36]. Moreover, less forceful generation of COP displacement in the anteroposterior (AP) and mediolateral (ML) directions has been observed in older adults[35,37–39]. Given that examining the changes in COP trajectories in the initiation of gait after TC training is necessary to understand the mechanisms of exercise-induced adaptation in the balance control system, the purpose of this study was to examine the changes in the translation of COP when older adults initiated gait after TC training.

SUBJECTS AND METHODS

Twenty healthy community-dwelling elderly (mean age, 74.1 ± 6.5 years; age range, 65–83 years) were recruited to participate in this trial. The participants who met the inclusion criteria underwent pre- and post-test measurements. The participants were included if they fulfilled the following inclusion criteria: a Berg Functional Balance Scale[40,41] Score > 50, a Frenchay Activities Index[42] Score > 50, a Physical Functioning Score of the SF-36 Health Surveys[43] > 20, and an age of 65 or older. All participants scored > 24 on the Mini Mental Status Exam (MMSE)[44]. Previous studies have demonstrated these tests are reliable and valid[45–47]. No participants showed neurological or orthopedic problems that prevented their participation. Subjects were excluded if they 1) had severe dementia (a MMSE score < 20); 2) were unable to complete 16 weeks of TC training due to severe or unstable medical conditions precluding participation, such as cardiopulmonary diseases or severe pain with weight bearing activities; 3) had a history of one or more falls in the previous 12 months; 4) had previous training in any form of TC or current involvement in any type of regular exercise program or were receiving physical therapy for musculoskeletal, neuromuscular, or balance dysfunctions; 5) were unable to walk independently; and 6) were unable to follow the testing procedures. Written informed consent was obtained from all the subjects and the University Institutional Review Board approved the study. Table 1 summarizes the demographic and selected functional characteristics of the participants.

Table 1. Baseline characteristics of the study participants

Participant details	Mean (SD)
Age (years)	74.1 (6.5)
Male/female	7/13
Height (cm)	159.8 (12.2)
Weight (kg)	55.3 (5.2)
BBS/56	54.6 (2.4)
FAI/60	52.5 (3.3)
PF/30	27.5 (1.5)
MMSE/30	27.2 (1.6)

Note. Values represent the mean ± standard deviation (SD). Abbreviations: BBS, Berg Balance Scale; FAI, Frenchal Activities Index; PF, Physical Functioning of the SF-36 Health Surveys; MMSE, Mini Mental Status Examination.

A certified TC leader and two assistants taught the 12 forms of Sun-style TC exercise[48] to the participants throughout the training period. The Sun-style TC exercise is being taught widely to help sufferers of arthritis and back pain, and to improve the balance of older people to prevent falls. It is well known for its smooth, flowing movements that omit the more physically vigorous crouching actions, and its gentle postures and high stances make it very suitable for geriatric exercise and martial arts therapy.

The TC program consisted of 15 minutes of warming-up exercise, 35 minutes of 12 easy-to-learn and easy-to-perform TC movements and 10 minutes of cooling-down exercise. The warm-up exercise comprised gentle stretches sequentially targeting the shoulder, neck, arms and legs followed by a torso stretching exercise that coordinated the weight shifts with trunk rotation, walking around with active arm swinging, and 5 minutes seated meditation with relaxed diaphragmatic breathing. The 12 simplified forms of TC training consisted of a series of slow, continuous and rhythmic graceful movements, emphasizing awareness of body coordination, smooth trunk rotation, multi-directional weight shifting, multi-segmental (arms, legs and trunk) movement coordination, and a gradual narrowing of the lower extremity stance. Synchronized breathing was also emphasized and integrated into each TC movement. The movements of the lower extremities were taught first to simplify the task complexity and allay subjects' safety concerns. When subjects could correctly perform the movements of the lower extremities, arm movements, breathing procedures and visual focus were added. Subsequently, 12 sequences selected from the Sun-style TC forms were practiced progressively within the context of the capability of subjects and the physiological effort that they were required to exert. The cycle of the 12 movements was repeated approximately 6 times during each practice session. Cooling-down exercises included a gentle and slow range of motion exercises of the ankles, knees and hips, as well as the back, and meditation, accompanied by relaxed diaphragmatic breathing. The TC instructor explained and demonstrated how each form of TC should be performed, and the group followed the motions. The participants met at the facility three times per week for a period of 16 weeks.

Two force platforms (AMTI, Newton, MA, USA) were placed adjacent to each other with the narrow edges embedded in a level walkway (5 m in length and 1.5 m in width) and three components of the ground reaction force (GRF) were measured at the initiation of gait. The amplified force platform signals were sampled on-line at a rate of 1,000 Hz for 5 seconds. The GRFs collected from the force platforms were processed and the COP (the point of application of the GRF vector on the force platform) data was analyzed using BioAnalysis v2.0 software (AMTI, Watertown, MA, USA).

For each trial, the participants stood quietly in a predetermined position with each foot on a force platform in a relaxed posture. Participants' feet on the force plate were traced. The tracings were used before the start of a new trial of GI for repositioning on the force plate to increase the consistency between-trials. The participants were then asked to begin initiating gait at their self-selected speed with the right limb in response to the verbal cue "GO", and continued to walk with the left limb. Each participant was instructed to complete two practice trials and approximately five successful experimental trials. All participants were instructed to wear flat-soled shoes normally used for everyday walking or sports activities.

Comparisons of the COP trajectories before and after TC training were conducted using the paired *t*-test. Statistical significance was accepted at $p < 0.05$. The parameters selected for analysis were the A-P and M-L displacement of COP. The A-P (or M-L) displacement of COP was defined as the total distance (or difference) between the minimum and maximum A-P (or M-L) COP location for the length of time that either the left or right foot was in contact with the force platform. Statistical software, SPSS 14.0 KO (SPSS, Chicago, IL, USA), was used for all statistical analyses.

RESULTS

The subjects who participated in the current investigation performed TC between August 2010 and December 2010. All participants completed the initial and post-intervention measurements. The data of all participants were used in the statistical analysis. No subject refused training and there were no adverse events reported during the 16-week TC training course. Significant differences in the COP displacement in the A-P and M-L directions were observed between pre- and post-TC intervention. A significant increase in these variables was observed in the post-intervention measurements compared to the pre-intervention measurements ($p<0.05$). The A-P COP displacements of the post-intervention were 114% and 136% of the values of the pre-intervention of the swing and stance limbs, respectively. The participants also showed increased M-L COP displacements of 114% and 141% of the values of both the swing and stance limbs before TC intervention, respectively.

Table 2 summarizes the mean values of the COP variables pre- and post-intervention.

Table 2. Means (± SD) for the COP variables of the swing and stance limbs at the pre- and post-intervention examinations

Dependent variables	Time	Values
Swing limb		
A-P displacement (cm)*	Pre-intervention	13.11 (2.94)
	Post-intervention	14.96 (2.17)
M-L displacement (cm)*	Pre-intervention	4.21 (1.47)
	Post-intervention	4.79 (1.83)
Stance limb		
A-P displacement (cm)*	Pre-intervention	15.54 (3.64)
	Post-intervention	21.18 (5)
M-L displacement (cm)*	Pre-intervention	4.6 (1.88)
	Post-intervention	5.25 (2.44)

Note. Values represent the mean ± standard deviation (SD). Abbreviations: COP, center of pressure; A-P, anteroposterior; M-L, mediolateral. *Significant difference ($p<0.05$) between pre- and post-intervention for the swing or stance limb.

DISCUSSION

The primary goal of this study was to determine the effects of TC training on GI by the elderly. The elderly subjects performed TC training, which incorporates elements that emphasize continuous flowing movement, balance control, endurance, strength, concentration and awareness of the environment. All 20 participants showed significant improvements in COP trajectories in GI. Compared to pre-intervention, the A-P and M-L COP displacements of the post-intervention increased significantly.

The COP variables measured in the present study are indicative of muscle responses for maintenance of dynamic stability in the initiation of gait. These variables have been used to measure the motor performance of both healthy and frail elderly. Previous studies[20,35] have reported that decreased sway of COP in either the A-P or M-L direction may indicate instability or perhaps the use of an alternative postural control strategy, which is possibly less efficient for the generation of momentum for the initiation of gait. The backward displacement of COP during GI is related to the generation of the forward moment necessary to initiate gait[49], and greater displacement of COP in the posterior direction increases the moment arm by which the GRF can move the COM forward[20].

In the current study, the participants improved their A-P displacements of COP for the right and left feet to averages of 14.96 cm and 21.18 cm, respectively. These findings are similar to those reported for level walking, stepping over an obstacle on the ground and descending stairs after TC training[20,50,51]. In those previous studies, Chris et al.[20] and Kim[50,51] reported increased posterior displacement of COP after TC training in both healthy and frail older adults when they initiated gait or descended stairs. Frail older adults, in particular, increased the magnitude of their A-P displacement of COP bringing it to closer to that reported for more healthy elderly subjects[20,50,51].

In the initiation of gait, the muscles of the lower extremities are activated stereotypically and create moments of force about the ankles and hip, which rotate the body[34,52–54]. Initially, there is an inhibition of the tonic soleus (SOL), which is active during the quiet stance, followed by the onset of tibialis anterior (TA) activity of both the swing and stance limbs. In older adults, this stereotypical pattern of the lower extremity muscle activity might not be observed as frequently as in healthy younger adults[39]. Inhibition of SOL did not precede the activation of TA when this stereotypical pattern was disrupted[39]. This lack of inhibition of SOL might be responsible for the reduced backward movement of COP[39]. Therefore, it is possible that the increased COP displacement in the A-P direction observed in those who received TC training might result from a restoration of the stereotypical pattern of the lower extremity muscle activity, SOL inhibition and TA activity, observed in GI.

COP displacement in the M-L direction and its effects on COM motion help maintain lateral stability when initiating gait, and the M-L COP variable might be compromised in individuals with postural instability[35,55–57]. Older adults with disability, those transitioning to frailty, and children with autistic disorders who exhibit less age-related development have reduced M-L displacements of COP[35,58]. Moreover, pregnant women with a history of falls also demonstrate a decrease in the movement of COP when responding to translational perturbation while standing on a movable platform[59]. In contrast, people with Parkinson's disease who have greater displacement of COP in the M-L and A-P directions tend to have a longer step length when initiating stepping[35]. Therefore, the changes in the displacement of COP observed in the present study may indicate increased dynamic postural stability of the participants after the TC training. In the current study, the mean displacement of COP in the M-L direction was 5 cm for both feet after TC training, a 14% increase compared to pre-intervention.

Although the muscle activity that produces greater displacement of COP in the M-L direction was not measured directly, the increased M-L COP displacement is likely to be the result of improved coordination of the hip abductor and adductor muscles[60]. In the initiation of gait, the stance-side (right limb in the current study) momentum is generated by the swing limb hip abductors that propel COP laterally toward the swing limb[34]. Therefore, muscle activities at the ankle and hip tend to propel the COM forward and toward the intended stance limb. A previous study reported that healthy older adults have a greater COP displacement toward the swing limb while performing level walking than those with disability[35]. The findings of our current study agree with the results of the previous studies[50,51] that demonstrated increased displacement of COP in the M-L direction in the performance of obstacle crossing and stair descent after TC training for healthy and fall-prone older adults.

This study had several limitations. The sample size was relatively small. Therefore, the power of the present study to detect subtle beneficial changes in TC training may be limited by the relatively small sample size. The lack of a control group and a convenience sample also limits interpretation of the results of the present study. Because all participants were healthy older adults living in the community, the present findings cannot be generalized to the entire population of frail elderly subjects or those with a history of falling. In addition, the 16 weeks of TC training used in the current study is a relatively short duration, and may not be sufficient for conferring the full benefit of TC training on older adults. It will be interesting to compare the findings of longer trials. No follow-up information to indicate whether the improvements were temporary or permanent was collected. In addition, this study did not measure the precise timing and spatial events of the gait parameters after TC training as only kinetic analysis was used. A collective analysis of the kinematic and kinetic data might provide more information about the influence of TC on dynamic balance control of the older population.

TC training is considered a form of moderate exercise that can be safely and easily conducted outdoors or indoors on an individual or group basis. It has rehabilitative potential as an effective strategy for reducing the likelihood of falls in the older population and to train older adults who have suffered hip fractures because of its proven beneficial effects on balance control, coordination and muscle strength. A well-designed randomized controlled trial using a larger population of older adults along with combined analysis of the kinematic and kinetic data is needed to obtain high quality evidence concerning the efficacy of TC training in fall prevention as well as a post-fracture training program for older people with and without a history of hip fractures.

In conclusion, this study has shown that participants in a 16-week TC training program demonstrated a significant increase in the displacement of COP in the A-P and M-L directions. These findings show that the 16-week practice of TC led to improvements in the participants' ability to generate momentum via a greater COP shift in the A-P and M-L directions as well as in the maintenance of balance and lateral stability when initiating gait. Improved balance control during GI may help older adults achieve better balance control when performing their daily activities. TC training may be effective for the prevention of falls among healthy elderly.

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