Abstract. [Purpose] The purpose of this study was to investigate the effectiveness of community-based Tai Chi (TC) training on balance control during stair descent by older adults. [Subjects] Participants were randomly assigned to either the TC group or the wellness education (WE) group. The participants in the TC group received TC training three times a week for 12 weeks. The participants in the WE group participated in a health education program for one hour weekly. [Methods] Subjects stood in a predetermined position at the top of a custom-built 3-step staircase and then negotiated the stairs at a self-paced speed. Participants were asked to place only one foot on each step (foot-over-foot). The changes in the translation of the center of pressure (COP) before and after TC training were measured. [Results] Subjects in the TC group showed a significant increase in the displacement of COP in the anteroposterior (A-P) and mediolateral (M-L) directions as well as average velocity of the COP displacement after Tai Chi training (p<0.01). There was little change in the COP displacement for subjects in the WE group. [Conclusion] These findings support the use of TC training as an effective fall prevention program to reduce the incidence of falls among the elderly. 

Key words: Balance, Falls, Tai Chi

INTRODUCTION

The incidence of falls increases with age\(^1\) and falls can result in severe consequences such as injuries, loss of functional independence, disabilities and even increased mortality\(^2\). Furthermore, subjects who fall can develop a fear of falling, which may cause the subjects to limit physical and social activities, leading to reduced mobility and physical fitness and to an increase in the actual risk of falling\(^3\). Falls by the elderly have also created important economic pressures on health systems as the total cost of all fall injuries for people 65 years and older exceeded $19 billion in the United States in 2000\(^4\) and the annual cost of fall injuries in the United States is expected to reach $54.9 billion by 2020\(^5\). Overall, fall-related injuries and associated health care costs present a serious public health problem. Minimizing falls and fall-related injuries among the elderly are therefore warranted.

Several studies have demonstrated that exercise improves balance control\(^6\) of the elderly. However, the effectiveness of these exercise programs as a means of fall prevention in older adults has been controversial. Some studies have demonstrated that exercise prevents falls\(^9\)\(^\text{-}14\), but other studies have shown no effect\(^15\)\(^\text{-}17\). Recently,
there has been growing interest in the use of Tai Chi (TC) as an exercise for improving postural balance and prevent falling among older people\textsuperscript{18–21}. TC is a traditional Chinese martial art that has been practiced for centuries as a health-promoting activity in Asian countries\textsuperscript{22}. The practice is characterized by a series of slow, gentle, continuous sequential movements shifting between double-leg and single-leg support, and TC emphasizes smooth integration of trunk rotation, coordination and dynamic weight. All of these movements require accurate joint control, body awareness, motor coordination, muscle coordination and good postural balance\textsuperscript{23}.

Stair negotiation is a common activity of daily life and falls on stairs are responsible for approximately 10% of all accident cases\textsuperscript{24,25}. The ability to negotiate stairs can be a quite challenging task when the elderly have reduced balance control and joint diseases of the lower extremities: for example, individuals affected by neuromuscular dysfunction, reduced visual capacity, osteoarthritis, joint or limb replacements and patellofemoral pain\textsuperscript{26,27}. Stair descent is the most challenging aspect of stair negotiation\textsuperscript{25,28} and is responsible for three-quarters of all staircase accidents\textsuperscript{24}, even though both stair ascent and descent are physically challenging tasks for the elderly. As compared to young adults, the elderly show similar peak vertical ground reaction force and joint moment at the knee, similar changes of plantarflexion and dorsiflexion angles at the ankle joint, and a lower joint moment at the ankle joint during the descent of stairs\textsuperscript{29–31}.

TC has been shown to be particularly effective in the prevention of falls and fall-related injuries among the elderly as its movement forms incorporate elements of balance control, postural alignment, concentration, strength, environmental awareness and endurance\textsuperscript{32}. Indeed, participation in Tai Chi has been shown to improve balance control\textsuperscript{33–36} and postural stability\textsuperscript{37}. However, no studies have been identified in the clinical literature that have specifically examined the effects of Tai Chi training on motor coordination and balance control during stair descent by the elderly.

The center of pressure (COP) is commonly used as an indicator of balance and postural control\textsuperscript{38} and decreased capability of generating COP displacement has been seen in the elderly\textsuperscript{39–42}. Changes in the translation of COP reflect the response of the central nervous system (CNS) to movement in the whole body center of mass (COM)\textsuperscript{40}. Thus, knowledge of changes in the translation of COP during stair descent after TC training may be useful for understanding the mechanisms of exercise-induced adaptation by the balance control system. The purpose of this study was to investigate the effectiveness of community-based TC training on balance control during stair descent by older adults.

**SUBJECTS AND METHODS**

Forty healthy community-dwelling elderly subjects (mean age, 75.8 ± 6.5 years; age range, 65–83 years) who were recruited from several assisted living facilities, volunteered to participate in this study. Participants were randomly assigned to either the TC group (n = 20, mean age, 74.3 ± 6.1 years; age range, 66–87 years) or the wellness education (WE) group (n = 20, mean age, 73.7 ± 5.5 years; age range, 65–82 years). The independent sample \( t \)-test demonstrated no significant difference in the age, height or weight of the participants between the TC group and the WE group. All participants underwent both pre- and post-intervention measurements with a prescheduled appointment.

Inclusion criteria for healthy elderly participants were a Frenchay Instrumental Activities of Daily Living\textsuperscript{43} score > 50, a Physical Function\textsuperscript{44} Score > 20 and a Berg Functional Balance Scale\textsuperscript{45,46} score > 50. The first two scores are based on the use of questionnaire tests, while the Berg Functional Balance Scale includes 14 basic mobility tasks. All participants scored greater than 24 on the Mini Mental Status Examination (MMSE)\textsuperscript{48}). These tests are considered reliable and valid based on previous studies\textsuperscript{48–50}. No participants presented with neurological or orthopedic problems that precluded them from participation in the study. By self-report, all participants reported having one or more falls in previous years. Exclusion criteria included the following: 1) presence of severe dementia (an MMSE\textsuperscript{47} score < 20); 2) the inability to complete 12 weeks of Tai Chi training due to physical illness; 3) previous training in any form of Tai Chi or current involvement in any type of regular exercise program; 4) contraindications to physical exercise, such as major orthopedic conditions (i.e., severe back, hip, knee, or ankle arthritis); and 5) inability to walk independently. All participants read and
signed an informed consent approved by the human ethics committee of the university prior to participation. Subject characteristics are summarized in Table 1.

Two experienced TC instructors and four assistants taught TC to the participants in the TC group. The TC training program consisted of 10 minutes of warm-up exercise, 40 minutes of 12 simplified Tai Chi movements and 10 minutes of cool-down exercise. The warm-up exercise included gentle stretches for the shoulder, necks, arms and legs followed by a trunk stretching exercise, a weight shift with trunk rotation, and active arm swinging. The 12 simplified forms of TC training comprised a series of slow, continuous and rhythmic graceful movements that best emphasized smooth trunk rotation, multidirectional weight shifting, multi-segmental (arms, legs and trunk) movement coordination and a gradual narrowing of lower extremity stance. Synchronized breathing was integrated into TC movement. The cycle of 12 movements was repeated for 40 minutes. The cool-down exercise consisted of the stretching of the arm and leg muscles, accompanied by deep abdominal breathing and relaxation. Instruction was given to learn new movements and review movements learned in previous sessions. Each TC practice session involved musical accompaniment.

The participants in the TC group performed the training three times weekly for 12 weeks. The participants in the WE group participated in a health education program for one hour weekly and attended lectures about diet and nutrition, fall prevention, exercise and balance, pharmacological management and mental health issues such as stress, depression and life changes. Participants in the WE group were instructed not to participate in any form of regular exercise program, but to maintain routine activities.

Participants negotiated a custom-built standard 3-step instrumented staircase. The dimensions of the staircase were as follows: step height, 17 cm; tread depth, 28 cm; tread width, 90 cm. Two force platforms (AMTI, Watertown, MA, USA), embedded in the first step of the staircase and in the level walkway (5 m in length and 1.4 m in width) directly in front of the staircase, measured the ground reaction forces during stair descent. Each step was independently constructed using a solid steel frame securely bolted to the ground. The vertical steel frames had a width and depth of 8 cm and 4 cm, respectively. This arrangement ensured a mechanically stiff structure that enabled forces to be recorded from the first step and the ground. Amplified force platform signals were sampled online at a rate of 1,000 Hz for 30 seconds (AMTI, Watertown, MA, USA). The COP was defined as the point of application of the ground reaction force vector in three directions on the force platform and was analyzed using BioAnalysis v2.0 software (AMTI, Watertown, MA, USA).

For each trial, subjects stood in a predetermined position at the top of the staircase. Participants were then asked to negotiate the stairs at a self-paced speed, with the left limb in response to auditory cues and continue for several strides after striking the force platform on the floor. Participants were instructed to place only one foot on each step (foot-over-foot). The analysis corresponded to the initial ground contact of the right foot on the second step down (first force platform) and the initial ground contact of the left foot on the floor (second force platform). This part of the analysis was chosen to represent a ‘steady-state’ step. Subjects completed two practice trials and approximately five successful experimental trials.

The independent sample t-test was used to compare the changes in the translation of the COP before and after Tai Chi training in participants of the TC group and the WE group. Statistical significance was indicated at p<0.05 and p <0.01. The dependent variables included anteroposterior (A-P) and mediolateral (M-L) displacement of the COP and the average velocity of the COP. The A-P (or M-L) displacement of the 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 foot or the right foot was in contact with the force platform. The average velocity of the COP was defined as the average velocity traveled by the locus

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Values are means ± standard deviations.
RESULTS

Statistical analysis determined significant differences between pre- and post-training measurements for both the A-P and the M-L displacement of the COP in the TC group (p<0.01, respectively). TC participants had a greater displacement of the COP in the A-P and the M-L directions for post-intervention measurements as compared to pre-intervention measurements (p<0.01, respectively). However, there were no significant differences in the A-P and the M-L displacement of the COP between pre- and post-intervention for the WE group participants (p>0.05, respectively). Furthermore, the average velocity of the COP for the TC participants was significantly greater for post-intervention measurements than the average velocity of the COP for pre-test measurements (p<0.01). However, statistical analysis found no significant differences between pre- and post-intervention measurements for the average velocity of the COP for the WE group participants (p>0.05). Changes in the displacement of the COP in A-P and M-L directions and the COP velocity before and after Tai Chi training for participants in the TC group and the WE group are summarized in Table 2.

DISCUSSION

No previous studies have examined the COP parameters for older adults that have descended a staircase before and after TC training. Control of the center of mass (COM) via translation of the COP during stair descent provides an important indication of dynamic postural stability. In this study, TC training led to significant increases in the A-P and M-L displacement of the COP as well as the average velocity of the COP in both the right foot and the left foot during stair descent.

The backward displacement of the COP during stair descent generates the forward momentum necessary to initiate gait51). In this study, TC group participants were able to improve A-P displacement of the COP an average 17.8 cm for both the right foot and the left foot, whereas the WE group participants showed little change in the A-P displacement of the COP between pre- and post-training. These observations are similar to observations made during level walking and while stepping over an obstacle on the ground after TC training33,34). In previous studies, Chris et al.33) and Kim34) have demonstrated increased backward movement of the COP after Tai Chi training in fall-prone adults. Interestingly, TC participants were able to increase the magnitude of the A-P displacement of the COP closer to the magnitude reported for more healthy elderly subjects52), whereas WE participants showed little change in the displacement of the A-P COP.

The average displacement of the M-L COP for the TC group participants was 10 cm for both the right foot and the left foot, a 52% increase as compared to pre-training. However, the WE group participants showed little change in the A-P displacement of the COP between pre-testing and post-training. This finding indicates that Tai Chi training positively influenced the magnitude of the M-L displacement of the COP. The greater displacement of the M-L COP is likely the result of improved coordinated action of the hip abductor and adductor muscles after TC training53). The stance-side momentum is generated during stair descent by the swing limb hip abductors that propel
the COP laterally toward the swing limb\textsuperscript{54}). Thus, muscle activity at the ankle and hip tend to propel the COM forward and toward the intended stance limb. The present findings are consistent with the findings of a previous study\textsuperscript{34}) that demonstrated increased M-L COP movement during obstacle crossing after Tai Chi training of fall-prone adults. Chris et al.\textsuperscript{33}) and Martin et al.\textsuperscript{40}) also reported that healthy older adults had an increased M-L COP during level walking as compared to older adults with balance impairment.

Previous studies\textsuperscript{55–57}) have reported that the control of the whole body COM in the M-L direction through manipulation of the COP during walking is important for the maintenance of lateral stability, which may be compromised in elderly subjects. It has also been argued that lateral body stability during obstacle crossing is a good indicator of balance impairment in the elderly\textsuperscript{58}).

The velocity of the COP provides valuable important information about how individuals modulate gait when negotiating various stairs. TC training resulted in a 26\% increase in the COP velocity for both the right foot and the left foot, which may reflect improvement in the maintenance of balance during stair descent, since a greater COP velocity was found during obstacle crossing by young adults as compared to the COP velocity of the elderly\textsuperscript{59}).

The current study had several limitations to the current study. The study had a relatively small sample size of older adults and a short duration of training. A further investigation with a larger sample size and long-term training is needed. Furthermore, a staircase containing three steps used in this study may not have allowed accurate evaluation of the descent of a typical staircase of a much longer length.

In conclusion, the findings of this study suggest that TC training influenced the generation of momentum via an increase in the magnitude of the COP movement in the A-P and M-L directions and the maintenance of balance, thereby improving the ability of older adults to descend stairs. TC training also resulted in an increase of the COP velocity during stair descent. Given these circumstances, the COP shift and velocity might be appropriate parameters that can be used to identify and to diagnose changes in the postural and locomotor systems. TC is widely accepted in Asia and is increasingly popular in Western cultures as a form of moderate exercise. TC can be performed safely at any age in any setting, has a low cost, is easy to execute, requires no equipment, and has great potential for socialization outdoors or indoors. Recently, evidence-based practice has been strongly emphasized in clinical practice. These findings support the use of TC training as an effective fall prevention program for the elderly and to counteract deficits in motor and sensory function associated with aging. Finally, in this study, only a subset of the parameters involved in the maintenance of balance was considered. Further studies should investigate the potential benefits of Tai Chi for other aspects of physiological changes such as muscle strength, flexibility, proprioception, vestibular inputs and sensory organizational changes, which might also affect balance.

REFERENCES


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