한국전문물리치료학회지 제 15권 제 4호
PTK Vol. 15 No. 4 2008

The Effect of Tai Chi Training on the Center of Pressure Trajectory While Crossing an Obstacle in Healthy Elderly Subjects

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Abstract

The purpose of this study was to investigate the changes of the center of pressure (COP) trajectory in healthy elderly subjects while crossing an obstacle before and after participation in Tai Chi training. Forty healthy elderly subjects participated either in a 12-week intervention of Tai Chi training or in a health education program. The participants were divided into two groups (the experimental group and the control group). Subsequently, the participants were pre- and post-tested on crossing over an obstacle from a quiet stance. Participants in the experimental group received Tai Chi training that emphasized the smooth integration of trunk rotation, a shift in weight bearing from bilateral to unilateral support and co-ordination and a gradual narrowing of the lower-extremity stance three times weekly. The participants in the control group attended a health education program one hour weekly and heard lectures about general information to promote health. Performance was assessed by recording the changes in the displacement of the COP in the anteroposterior (A-P) and mediolateral (M-L) directions using a force platform. Participants in the Tai Chi group significantly increased the A-P and M-L displacement of the COP after Tai Chi training ($p<.05$). No significant differences in the A-P and the M-L displacement of the COP between pre-testing and post-testing in the control group were found. This study has shown that participation in Tai Chi exercise increased the magnitude of the A-P and M-L displacement of the COP, thereby improving the ability of healthy elderly participants to generate momentum to initiate gait. These findings support the use of Tai Chi training as an effective fall-prevention program for the elderly.

Key Words: Center of pressure; Falls; Gait initiation; Obstacle crossing; Tai Chi training.

Introduction

Falls in the elderly are among the most important health problems as they can result in injuries, loss of functional independence, disabilities and even increased mortality (Campbell et al, 1990). Each year, 25~33% of persons aged 65 years and over are involved in a fall at least once a year (Bernstein and Schur, 1990; Englander et al, 1996) and 25~33% of subjects that have fallen are more likely to fall again (Nevitt et al, 1989; O'Loughlin et al, 1993). Falls in the elderly are also an important economic pressure on the health system as fall-related injuries result in a total cost of 7.8 billion U.S. dollars (Rice and Mackenzie, 1989) and the total annual cost of a hip fracture related to a fall in the United States is projected to reach 82~240 billion U.S. dollars by the year 2040 (Schneider and Guralnik, 1990). Therefore, preventing falls in the elderly and controlling associated health care costs are very important health issues for individuals, families and society.

Recently, the use of Tai Chi has received increased attention as a potentially effective exercise for fall prevention and an enhancement of human well-being among older people (Hartman et al, 2000; Kutner et al, 1997; Tsang and Hui-Chan, 2003;

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This work was supported by the Korea Research Foundation Grant funded by the Korean Government (KRF-331-E00187).

Wolf et al, 2003). Tai Chi is an ancient Chinese martial art that has been practiced for centuries for the promotion of human health in Asian countries (Koh, 1981). It consists of a series of slow, gentle, continuous graceful movements transitioning from double-limb to single-limb support and thus emphasizes smooth integration of trunk rotation, coordination and dynamic weight. Participation in Tai Chi has been shown to be effective in the reduction of falls and fall related injuries in the elderly by improving balance control (Hass et al, 2004; Tse and Bailey, 1992; Wolfson et al, 1996) and postural stability (Wolf et al, 1997).

Nevertheless, only a few studies have specifically examined the effects of a Tai Chi exercise program on motor coordination and postural control (Hass et al, 2004; Mak and Ng, 2003; Wu et al, 2002). Furthermore, despite that Tai Chi exercise has been reported to improve balance and reduce falls in the elderly, previously published reports have not discussed potential underlying mechanisms for the improved abilities of the elderly for balance and postural stability. One possible approach to investigate the influence of Tai Chi training on balance and postural stability in the elderly is to examine the displacement of the center of mass (COM) and the center of pressure (COP) or the relationship between these parameters. Changes in the COP represent the response of the central nervous system (CNS) to movement in the entire body COM (Martin et al, 2002).

There have been no previous studies on how Tai Chi training changes the COP trajectory in healthy elderly during obstacle crossing, a task that would place a higher risk on falls. The purpose of this study was to investigate the changes of the COP trajectory in healthy elderly subjects while actually crossing an obstacle before and after participation in a 12-week Tai Chi training program.

Methods

Subjects

Forty healthy community-dwelling elderly subjects (mean age, 78.2±8.2 years; age range, 65~85 years) participated in this study. Participants were randomly assigned to either an experimental group (Tai Chi group) (mean age, 77.8±8.9 years; age range, 65~85 years) or a control group (mean age, 78.6±7.5 years; age range, 65~82 years). The use of independent sample t-tests demonstrated no significant difference in age, height, or weight in the participants between the Tai Chi group and control group ($p>.05$). The participants underwent pre-testing measurements. All participants from both the Tai Chi group and the control group completed all of the post-testing measurements.

Inclusion criteria for consideration as a healthy elderly participant were a Berg Functional Balance Scale score>50 (Berg et al, 1989; 1992), a Frenchay Instrumental Activities of Daily Living score>50 (Schuling et al, 1993) and a Physical Function score>20 (Ware and Sherbourne, 1992). All participants scored greater than 24 on the Mini Mental Status Examination (MMSE) (Folstein et al, 1975). These tests are considered reliable and valid based on previous studies (Tombaugh and McIntyre, 1992; Turnbull et al, 2000; Yip et al, 2001). The Frenchay Instrumental Activities of Daily Living have the reliability (internal consistency) of .78~.87 and the validity (construct) of .75~.86 (Schuling et al, 1993). The Physical Function (SF-36) has the reliability (internal consistency) of .80~.92 (Garratt et al, 1993) and the validity (construct) of .93 (Brazier et al, 1992). The participants had no neurological or orthopedic problems that prevented them from participation in the study. By self-reporting, all elderly participants reported no falls in the previous 12 months. Exclusion criteria were; 1) severe dementia (an MMSE score<20) (Folstein et al, 1975), 2) inability to complete 12 weeks of Tai Chi training due to a physical illness, 3) previous training in any form of Tai Chi or current involvement in any type

of regular exercise program, 4) the subject was unable to walk independently. All participants signed an informed consent form approved by the University Institutional Review Board prior to participation. The subject characteristics are summarized in Table 1.

Interventions

A certified Tai Chi instructor and four assistants taught the 12 forms of Tai Chi training to the subjects in the Tai Chi group. The Tai Chi training program included ten minutes of warm-up exercise, 40 minutes of 12 Tai Chi movements and ten minutes of cool-down exercise. The warm-up exercise consisted of gentle stretches for the shoulder, necks, arms, and legs followed by a trunk stretching exercise, weight shift with trunk rotation and active arm swinging. The 12 forms of Tai Chi training comprise a series of slow, continuous, and rhythmic graceful movements that emphasize the smooth integration of trunk rotation, a shift in weight bearing from bilateral to unilateral support, and coordination and a gradual narrowing of the lower-extremity stance.

The cool-down exercise included the stretching of the arm and leg muscles and a diaphragmatic breathing exercise. The participants in the Tai Chi group performed training three times weekly for 12 weeks. In place of participation in the exercise program, the participants in the control group attended a health education program one hour weekly and heard lectures about diet and nutrition, physical activity, fall prevention, and general health information. Participants in the control group were required not to participate in any form of regular exercise program and to maintain routine activities.

Equipment

A force platform[1)], embedded in a level walkway (5 m in length and 1.22 m in width), measured ground reaction forces of walking. Amplified force platform signals were sampled on-line at a rate of 1000 ㎐ for 5 seconds. The COP data were analyzed using BioAnalysis version 2.0 software (Advanced Mechanical Technology, Inc., Watertown, MASS, U.S.A.). An obstacle (18 ㎝ in height, 10 ㎝ in depth, and 140 ㎝ in width) was used for obstacle crossing.

Procedures

The experimental setup is shown in Figure 1. For each trial, participants stood in a predetermined position with feet on a force platform and then in response to auditory cues, stepped over an obstacle at a self-paced speed with the right limb. Participants completed two practice trials and five successful experimental trials.

Statistical Analysis

Independent sample t-tests were used to compare the changes in the COP trajectory before and after Tai Chi training for the participants of the Tai Chi group and the control group. Statistical significance was indicated at $p<.05$. Independent variables included the A-P and M-L displacement of the COP.

Table 1. Subject characteristics (N=40)

Group	N	Age (years)	Sex (male/female)	MMSE[b]	BFBS[c]	FIADL[d]	APF[e]
Tai Chi	20	77.8±8.9[a]	10/10	29.0±1.0	55.6±0.5	53.7±1.0	27.6±1.6
Control	20	78.6±7.5	8/12	28.9±1.1	54.9±1.0	52.8±1.2	27.2±1.9

[a]Mean±SD.
[b]MMSE: Mini Mental Status Examination.
[c]BFBS: Berg Functional Balance Scale.
[d]FIADL: Frenchay Instrumental Activities of Daily Living.
[e]APF: Assessment of Physical Function.

1) Advanced Mechanical Technology, Inc., Newton, MASS, U.S.A.

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 either the left or right foot was in contact with the force platform. Statistical software SPSS 14.0 KO (SPSS, Chicago, IL, U.S.A.) was used for all statistical analyses.

Results

There were significant differences between the pre-testing and post-testing measurements in both the A-P and the M-L displacement of the COP in the Tai Chi group ($p<.05$, respectively). Both the A-P and the M-L displacement of the COP for the post-testing measurements were significantly greater than the A-P and the M-L displacement of the COP for the pre-testing measurements ($p<.05$, respectively). However, no significant differences in both the A-P and the M-L displacement of the COP between the pre-testing and post-testing measurements in the control group were found. Changes in the A-P and M-L displacement of the COP before and after Tai Chi training in the Tai Chi group participants and the control group subjects are summarized in Table 2.

Discussion

The primary goal of this study was to examine how healthy elderly subjects modulate the COP trajectory on obstacle crossing before and after 12-weeks of Tai Chi training. The elderly subjects in the Tai Chi group significantly increased the displacement of the A-P and M-L of the COP in post-test measurements as compared to the pre-testing measurements. Participants in the Tai Chi group were able to increase the mean displacement of the A-P and M-L COP in post-testing by 28% and 23%, respectively, as compared to pre-testing. In contrast, the control group subjects showed little change in the A-P and M-L displacement of the COP between pre-testing and post-testing.

A previous study (Hass et al, 2004) has demonstrated that fall-prone older adults increased backward movement of the COP after Tai Chi training. The magnitude of the backward displacement of the A-P COP was increased in Tai Chi participants, but no change in the displacement of the A-P COP was observed for subjects who only participated in a wellness education program instead of Tai Chi training (Hass et al, 2004). The backward displacement of the COP in early phase of gait initiation (GI) generates the forward moment necessary to initiate stepping (Polcyn et al, 1998). During GI, the A-P

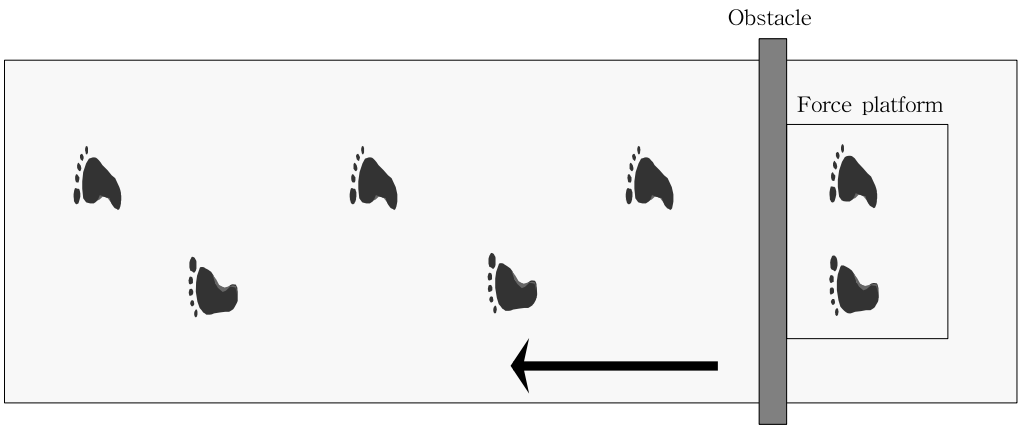

Figure 1. Experimental setup. A dark arrow indicates the direction of movement.

movement of the COP is caused by an inhibition of the tonic soleus and an activity of tibialis anterior of both the swing and stance limbs (Breniere and Do, 1986; Brunt et al, 1991; Crenna and Frigo, 1991). Such a decrease in the magnitude of the displacement of the A-P COP and in forward momentum observed in the control group of subjects would result from reduced inhibition of the tonic soleus and gastrocenmius activity, decreased tibialis anterior activity and increased ankle joint stiffness related to aging (Brunt et al, 2005; Shephard et al, 1990).

A previous study (Martin et al, 2002) demonstrated that older adults had a significantly reduced M-L displacement of the COP during GI as compared to young adults. The average displacement of the M-L COP for the Tai Chi group subjects was 22.71 ㎝, a 4.21 ㎝ increase as compared to the value determined at pre-testing. However, no change in the M-L displacement of the COP between pre-testing- and post-testing measurements in the control group subjects was observed. These findings indicate that the participation in Tai Chi training positively influenced the magnitude of the M-L displacement of the COP. This increased M-L displacement of the COP may be due to a better performance of muscle activity at the ankle and hip, which can propel the COM forward and toward the intended stance limb during the initial stage of GI (Winter et al, 2003).

Conclusion

The Tai Chi group of subjects increased the magnitude of the A-P and M-L displacement of the COP, thereby improving the ability of healthy elderly subjects to generate momentum to initiate gait. Tai chi is considered as a form of moderate exercise for the elderly that can be performed safely with a low cost, ease of application, and great potential for socialization outdoors or indoors on an individual or group basis to improve balance and to prevent falls. Recently, the use of evidence-based practice is strongly emphasized in clinical practice. These findings support that the use of Tai Chi training could be an effective fall-prevention program to reduce falling in the face of declining functional and physical abilities in the elderly and to counteract deficits in motor and sensory function associated with aging. Finally, the potential benefits of Tai Chi for important geriatric diseases, such as suffered hip fracture, osteoarthritis, chronic pain and dementia remains unclear. Future studies are warranted to investigate the effectiveness of Tai Chi training in the elderly with these and other diseases.

Table 2. The COP (center of pressure) parameters (㎝) during obstacle crossing in pre-testing and post-testing

Dependent variables	Group	Time	Value
A-P (anteroposterior) displacement	TCG[b]	Pre-testing	13.63±2.88[a]
		Post-testing	17.45±2.88*
	CG[c]	Pre-testing	13.85±2.15
		Post-testing	13.58±2.13
M-L (mediolateral) displacement	TCG	Pre-testing	18.50±5.03
		Post-testing	22.71±3.98*
	CG	Pre-testing	17.96±4.33
		Post-testing	17.79±2.59

[a]Mean±SD.
[b]TCG: Tai Chi group.
[c]CG: Control group.
*$p<.05$ for a change as compared with the pre-testing.

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This article was received September 9, 2008, and was accepted October 28, 2008.