Tai Chi practitioners have better postural control and selective attention in stepping down with and without a concurrent auditory response task

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Abstract

To compare the performance of older experienced Tai Chi practitioners and healthy controls in dual-task versus single-task paradigms, namely stepping down with and without performing an auditory response task, a cross-sectional study was conducted in the Center for East-meets-West in Rehabilitation Sciences at The Hong Kong Polytechnic University, Hong Kong. Twenty-eight Tai Chi practitioners (73.6±4.2 years) and 30 healthy control subjects (72.4±6.1 years) were recruited. Participants were asked to step down from a 19cm high platform and maintain a single-leg stance for 10 seconds with and without a concurrent cognitive task. The cognitive task was an auditory Stroop test in which the participants were required to respond to different tones of voices regardless of their word meanings. Postural stability after stepping down under single- and dual- task paradigms, in terms of excursion of the subject's center of pressure (COP) and cognitive performance, was measured for comparison between the two groups. Our findings demonstrated significant between-group differences in more outcome measures during dual-task than single-task performance. Thus, the auditory Stroop test showed that Tai Chi practitioners achieved not only significantly less error rate in single-task, but also significantly faster reaction time in dual-task, when compared with healthy controls similar in age and other relevant demographics. Similarly, the stepping-down task showed that Tai Chi practitioners not only displayed significantly less COP sway area in single-task, but also significantly less COP sway path than healthy controls in dual-task. These results showed that Tai Chi practitioners achieved better postural stability after stepping down as well as better performance in auditory response task than healthy controls. The improved performance that was magnified by dual motor-cognitive task performance may point to the benefits of Tai Chi being a mind-and-body exercise.

Keywords: older adults, dual-task, postural stability, auditory Stroop test, stairs

INTRODUCTION

The incidence of falls increases with age and the resulting annual health cost in the UK escalates from £0.3 million per ten thousand population at age 60 to 64 to £1.5 million among those aged more than 75 (Scuffham et al., 2003). Aside from medical cost, falls in older adults lead to physical and psychological consequences such as decreased quality of life, fear of falling and related inactivity, and social isolation (Zijlstra et al., 2008). Therefore, falls among the elderly are gaining increasing attention among researchers and clinicians. Previously, fall risk factors were only considered in terms of physical aspects such as attenuated sensory inputs, decreasing muscle strength, and deficits in balance control. During the past decade, more and more investigators have come to believe that cognitive elements also contribute significantly to fall risk (Anstey et al., 2006; van Schoor et al., 2002).

Dual-task designs for assessing postural control with concurrent cognitive processing have been adopted to compare younger with older adults performing a specific cognitive task while standing (Hauer et al., 2003; Shumway-Cook and Woollacott, 2000), walking (Kelly et al., 2008; Siu et al., 2008, 2009; van Iersel et al., 2007), or in response to postural perturbation (Maki et al., 2001; Rankin et al., 2000; Redfern et al., 2002; Zettel et al., 2008). The findings from such dual-task studies show that older subjects manifest both physical and cognitive deterioration when compared with younger subjects.

Negotiating stairs is a difficult daily activity for many older subjects (Startzell et al., 2000; van Iersel et al., 2003). More specifically, more than 10% of fatal falls among older adults occur while descending stairs (Startzell et al., 2000). Studies have found that older adults need more motor arousal during stair descent (Hortobágyi and DeVita, 2000), which is related to their relative lack of attention to such tasks. For example, Ojha and

colleagues (2009) found that older subjects required more attentional resources than healthy young adults while negotiating stairs. If so, would descending stairs affect the performance of a cognitive task in older subjects?

The positive effects of Tai Chi training on postural control have been demonstrated in terms of improved muscle strength, joint proprioception, and sensory organization ability, all of which contribute to postural control (Chen et al., 2012; Li et al., 2005; Tsang and Hui-Chan, 2004). Tai Chi is a mind-body exercise that demands motor planning in performing very precisely a prescribed sequence of movement patterns (Tsao, 1995). For example, Tai Chi practice requires the mind to concentrate on the ordering of coordinated eye-limb (hand and leg) and eye-body (neck and trunk) movements in a smooth sequence (Li et al., 2001). Previous findings in our own laboratory have shown that Tai Chi practitioners have less disturbance in the pre-landing muscle response latency during stepping down while performing a concurrent mental task when compared with older controls (Tsang et al. 2012). They are also found to have better attention and memory than controls (Man et al., 2010). Also, a recent prospective study found that after 3 months of Tai Chi practice, older subjects achieved improvement in global cognitive function and delayed recall, and had fewer subjective cognitive complaints. Further, improvements in visual span and Clinical Dementia Rating scores were only observed among the Tai Chi group, not among those practicing stretching as controls (Lam et al., 2011).

The ability to maintain postural stability after stepping down is important for older adults from a safety point of view, especially when they are required to perform a concurrent cognitive task such as responding to a family member calling them to come

down for dinner from their bedroom upstairs. Also, older subjects are known to require more attentional resources than younger subjects when negotiating stairs (e.g. Ojha et al. 2009). The mental and physical demands of Tai Chi suggest that Tai Chi practitioners may have improved both in physical and cognitive performance. A question naturally arose: Could Tai Chi practitioners maintain better postural control after stepping down and also better cognitive performance while performing a dual stepping down with a concurrent cognitive task which was auditory in nature? We hypothesize that Tai Chi practitioners might show better postural control and also better cognitive performance than healthy controls after a stepping down activity with and without a concurrent auditory task.

METHODS

Participants

This was a cross-sectional study with a total of 58 healthy and active older participants. The subjects were all independent in their activities of daily living. Among them, 28 were Tai Chi practitioners (9 males and 19 females) who were recruited from two local Tai Chi clubs. All of them had practiced Tai Chi for a minimum of 1.5 hours per week for at least 3 years (average Tai Chi experience = 6.7±4.6 years). The other 30 control subjects (7 males and 23 females) were recruited from elderly centers and had no Tai Chi experience. Candidates were excluded if they had any neurological disorder, myocardial infarction, heart failure, uncontrolled diabetes or hypertension, any deformity of a hip or knee, or any cognitive or hearing problem. Subjects who suffered dizziness on the day of data collection or who could not follow verbal commands were also excluded.

This study was approved by the Ethics Committee of The Hong Kong Polytechnic University. The procedures were fully explained, and written, informed consent was obtained from all of the participants.

Procedures

Each participant underwent an auditory Stroop test, and then a stepping down task with and without a concurrent auditory Stroop test, as described below.

Auditory Stroop test

The color-word version of the test was first used by Stroop in 1935. He was able to demonstrate that when the name of a color was displayed in a color not corresponding to the name, naming the color of the word took longer and people made errors more readily. The test has since clearly been shown to demand executive attention (Siu et al., 2008), so the auditory version of the test was chosen in the present study. The tests included two Cantonese words meaning “high” and “low” and were pronounced at either a high or low pitch. (Cantonese is a tonal language, so the subjects, all native speakers of some Chinese language, can be assumed thoroughly sensitive to pitch differences.) The subjects were asked to press the right hand thumb switch when hearing a high pitch pronunciation and press the left thumb switch on hearing a low pitch pronunciation, disregarding the meaning of the word pronounced.

Four familiarization trials were practiced for each combination of meaning and pitch were conducted with the subject sitting in a quiet room before testing began. During

the subsequent testing, reaction time (RT) was defined as the time from the appearance of the sound to the time when the subject pressed the button. If a subject pressed the right-hand button when the pitch was low or the left-hand button when the pitch was high, it was counted as an incorrect response. Altogether 16 trials were conducted with each participant and the average reaction time and error rate (percentage of wrong responses) for each group were calculated.

Stepping down task

The subjects were asked to step down with their dominant leg from a 19cm high platform onto a force plate (Model OR6-5-1000, Advanced Mechanical Technologies Inc., Newton, MA) placed in front of the platform. The dominant leg was defined as the leg that was used to kick a ball (Tsang and Hui–Chan, 2005). Moments and reaction forces were recorded with the force plate at a sampling frequency of 1,000Hz. The CoP coordinates along the anteroposterior (CoPx) and mediolateral direction (CoPy) were calculated as follows: CoPx = -My/Rz and CoPy = Mx/Rz; where Mx and My are the moments perpendicular to the anteroposterior and mediolateral directions, respectively, and Rz is the vertical component of the ground reaction force. Visual fixation was used to standardize subjects' attention before and after stepping down. Before they stepped down, subjects were asked to stand with shoulder width and look at a fixed visual target placed 2 meters away from the center of the force plate. After they stepped down, subjects were again required to look at the visual target for gaze stabilization. During stepping down, no additional visual fixation was required. Subjects were instructed to step down onto the force plate using their dominant leg in response to an audio cue, and then remain in

single-leg stance for 10 seconds. They were asked to keep their non-dominant leg clear of the platform throughout (Figure 1).

In order to determine the influence of pressing the thumb switch on posture control, the subjects were asked to press a thumb switch (without any Stroop test) during the stepping down task, from hearing the audio cue to the moment of landing on the force plate. Familiarization trials were again given before data recording. Rests were provided as needed. A total of four trials were conducted.

The data were recorded and analyzed using version 8.6 of the Lab-View (NI USB 621, National Instrument Corp., Austin, TX, USA). Group averages were computed for comparison between the two subject groups.

Stepping down with a concurrent cognitive task

Under the dual-tasks paradigm, subjects were asked to respond to the auditory Stroop test as quickly and as accurately as possible while performing the postural task. The auditory test was administered either when subjects lifted their leading leg (detected by pressure sensors positioned underneath subject's heels [force sensing resistor, model FSR406, 44 mm x 44 mm, Interlink electronics, USA]) or when they stepped onto the force plate (triggered by the force plate). A total of eight trials were conducted with each subject. The subjects were told that Stroop test word might be heard at any time during the stepping down and single leg stance.

The COP trajectory during the first 5 seconds of the single leg stance was analyzed. The 5 second duration was adopted because the average single leg stance time of such older subjects was known to be about 6 to 7 seconds (Li et al., 2005). Two body

sway measures were used to evaluate balance control performance after stepping down: 1) total sway path of the COP; and 2) the sway area, which was the area under the maximum sway excursion. The time needed to stepping down was also recorded. This was defined from the moment when the leading leg left the step to when it stepped onto the force plate. The sequencing of the different conditions during the trials was randomized.

Statistical analysis

All the analyses were performed using version 17.0 of the commercially available Statistical Package for the Social Sciences (SPSS) software (IBM Corp., Armonk, NY, USA). Continuous data were expressed using their mean and standard deviation. Age, weight, and height were compared between the experienced Tai Chi practitioners and the control subjects using independent *t*-tests. A chi-square test was used to compare the sex distributions and physical activity levels of the groups. Repeated measures multi-variate analysis of variance (MANOVA) was used to compare the results observed in the stepping down task, the auditory Stroop tests, and the dual stepping down and auditory tasks between the Tai Chi and control subjects. If a statistically significant overall difference was found, univariate tests were conducted for each of the measures. A significance level (α) of 0.05 was chosen for statistical comparisons.

RESULTS

Participants

Fifty-eight older adults participated in this study. Table 1 shows that the controls and the experienced Tai Chi practitioners did not differ significantly in terms of their average age, height, weight, Mini-Mental Status Examination (MMSE) score, or physical activity level (all $p>0.05$). The Tai Chi practitioners had an average of 6.7 years of experience.

Auditory Stroop test

Repeated measures MANOVA showed an overall group x task difference ($p=0.043$) in the groups' auditory Stroop test results. Univariate analysis demonstrated that there was a statistically significant difference in the group x task in reaction times but not in the error rates (Table 2). Paired-t tests showed that all the participants had increased average reaction times and error rates in the dual- versus single-task. Independent t-tests showed that while the average error rates in the auditory Stroop test manifested significant between-group differences in both the single- and dual-task conditions, average reaction time showed a significant between-group difference only in the dual tasks condition (Table 2).

Stepping down performance with single- and dual-task paradigms

All the participants could complete the stepping down task and were able to maintain the single leg stance for at least 5 seconds. The time required to step down under single- and dual-task conditions showed no significant inter-group difference ($p=0.921$ and $p=0.320$, respectively; data not tabulated). Since the two groups used similar time to

complete the stepping down task, it was therefore not treated as a co-variate in the subsequent analysis.

Repeated measures MANOVA showed no significant group x task difference in the stepping down results ($p>0.05$). The total sway path of the COP under dual-task did show a significant between-group difference ($p=0.033$; Table 3) but not while single-task. The sway area with both single- and dual-task both showed a significant between-group difference ($p=0.014$ and 0.034, respectively (Table 3).

DISCUSSION

The aim of this study was to investigate the performance of older Tai Chi practitioners in a stepping down task with and without a concurrent cognitive task and compare it with the performance of controls similar in age and physical activity level. Based on previous findings, Tai Chi practice can improve postural control (Tsang and Hui-Chan, 2004, 2005), as well as cognitive function in community-dwelling older adults (Man et al., 2010) and those with cognitive impairments (Lam et al., 2011). However, whether Tai Chi practitioners would show better postural control than healthy controls after stepping down was unknown. Whether they would show better performance after stepping down while doing a cognitive task was also tested.

Cognitive performance

The results show that the Tai Chi practitioners had response times similar to those of healthy controls when the auditory Stroop test alone was administered while seated (Table 2). When an additional postural task was being performed simultaneously, both

groups showed significantly slower response times, but the Tai Chi practitioners showed significantly faster response times than the controls on average (Table 2). In this connection, Ojha and collaborators (2009) combined a verbal response task with a stair walking (both up and down) and found that healthy older subjects responded more slowly to an auditory tone during stair walking. The magnitude of the increase, which they termed “attentional cost”, was about 53%. In this study the response time of the Tai Chi practitioners increased by 61% on average, while that of the controls increased by 80% when compared with single-task performance. The larger increase observed in this study could be due to the difference in complexity of the cognitive tasks between the two studies. In the study by Ojha’s group, the cognitive task was a direct reaction to a voice, which would have involved relatively simple cognitive processing. In contrast, the Stroop test conducted in this study called on the executive function of the cortex (Siu et al., 2008), which Royall and his colleagues (2002) describe as involving planning, initiation, sequencing and monitoring of complex goal-directed behavior. The Stroop test, especially the incongruent test during which the meaning of the word did not match the pitch of the voice, requires subjects to inhibit a direct response and react with a substituted response (Siu et al., 2009). Compared to a direct response to a voice, the task requires more attentional processing, which may lead to an increase in the response time.

The Tai Chi practitioners made significantly fewer mistakes than the healthy controls in both the single- and dual- task Stroop tests (Table 2). The auditory Stroop test requires executive attentional resources which demand that subjects selectively inhibit an automatic response (Siu et al., 2009). In a previous study, experienced elderly Tai Chi practitioners displayed significantly better attention and memory than other healthy

elderly with or without regular exercise training (Man et al., 2010). This may explain why the Tai Chi subjects showed a lower average error rate than the healthy controls.

Stepping down performance

Neither group showed a significant increase in body sway during dual-task compared with their single-task performance. Previous studies investigating postural control using a dual-task paradigm have shown conflicting results. Some investigators have found that with the addition of a cognitive task, postural control deteriorates in either a perturbed (Redfern et al., 2001) or un-perturbed condition (Shumway-Cook and Woollacott, 2000). Their proposed explanation is that postural control and cognitive activity compete for attentional resources, so during dual-task performance postural control performance is constrained by the sharing of limited attentional resources (Kahneman, 1973; Tsang et al., 2011). In contrast, other investigators have found improved balance control in dual-task situations (Deviterne et al., 2005; Melzer et al., 2001). Huxhold and colleagues (2006) have suggested that the efficacy of cognitive processing in postural control could be influenced by the difficulty, modality and stimulus of the concurrent cognitive task, and also any postural constraints affecting the concurrent cognitive task. In the present study the subjects were required to perform a comparatively difficult postural task and a cognitive task with high attentional demands. The results show that the subjects' cognitive performance was being affected significantly more (Table 2) than their postural control performance, which was negligibly affected during dual-task versus single-task performance (Table 3). This could demonstrate that the older adults prioritize postural control. Such a conclusion would be in line with previous

findings that older adults prioritize postural control by sacrificing cognitive processing in dual-task performance, especially when the demand of the postural task is high (Lacour et al., 2008). In this study, excessive body sway in stepping down could have led to falling (Brown et al. 2002; Lacour et al., 2008).

The stepping down performance of the Tai Chi practitioners

This has been the first published study to investigate the relationship between Tai Chi practice and postural control after stepping down using a dual-task paradigm. Under single-task condition the Tai Chi practitioners demonstrated less body sway in terms of the COP area generated during the single-leg stance period after stepping down compared with the healthy controls (Table 3). They also performed better in the dual-task condition in terms of both COP path and area. Practicing Tai Chi has been found to improve postural control in older adults as measured by single-leg stance time (Gyllensten et al., 2010; Li et al., 2005; Schaller, 1996; Song et al., 2003). It follows that during single-leg stance after stepping down (the single-task condition), the Tai Chi practitioners should have demonstrated better postural performance than the healthy controls, and this was indeed shown by their smaller average COP area (Table 3). One would expect the difference to be even more significant during dual-task, and indeed Table 3 shows that the Tai Chi practitioners had significantly shorter COP paths and smaller areas, on average, than the healthy controls similar in age, height, weight, gender distribution, and physical activity level (Table 1). The mind-body principle of Tai Chi aims to train up motor planning and movement sequencing during the different Tai Chi forms (Wolf et al., 1997).The demand for mental concentration during Tai Chi practice might be expected to

help practitioners achieve better performance in both postural and cognitive tasks during dual-task performance, as shown by the findings here.

This was a cross-sectional study, so no cause-effect relationship could be established using these protocols. No young healthy subjects were recruited for comparison, so the aging effects on stepping down and auditory response could not be investigated. Although the MMSE was employed for screening the cognitive level of the participants, more general cognitive tests (Man et al., 2010) can be employed in the future study to compare the two older adult groups. In this study, whether Tai Chi practice improves postural control in the corrective postural adjustments phase (Yiou et al., 2009) and/or during whole body maintenance during single-leg stance phase was not differentiated. Further analysis is warranted.

This study has been the first investigating postural control after stepping down with both single- and dual-task. The main finding is that older adults who practice Tai Chi perform consistently better in the postural control after stepping down task whether or not there is a concurrent auditory task. Their cognitive performance was also better under both conditions. The present findings form the basis to conduct a randomized clinical trial investigating the effects of Tai Chi practice on improving postural control and cognitive performance in stepping down under a dual-task paradigm. If Tai Chi practice is proven effective, it can enhance the management of falls prevention which might lead to the reduction of health care cost and suffering of older adults.

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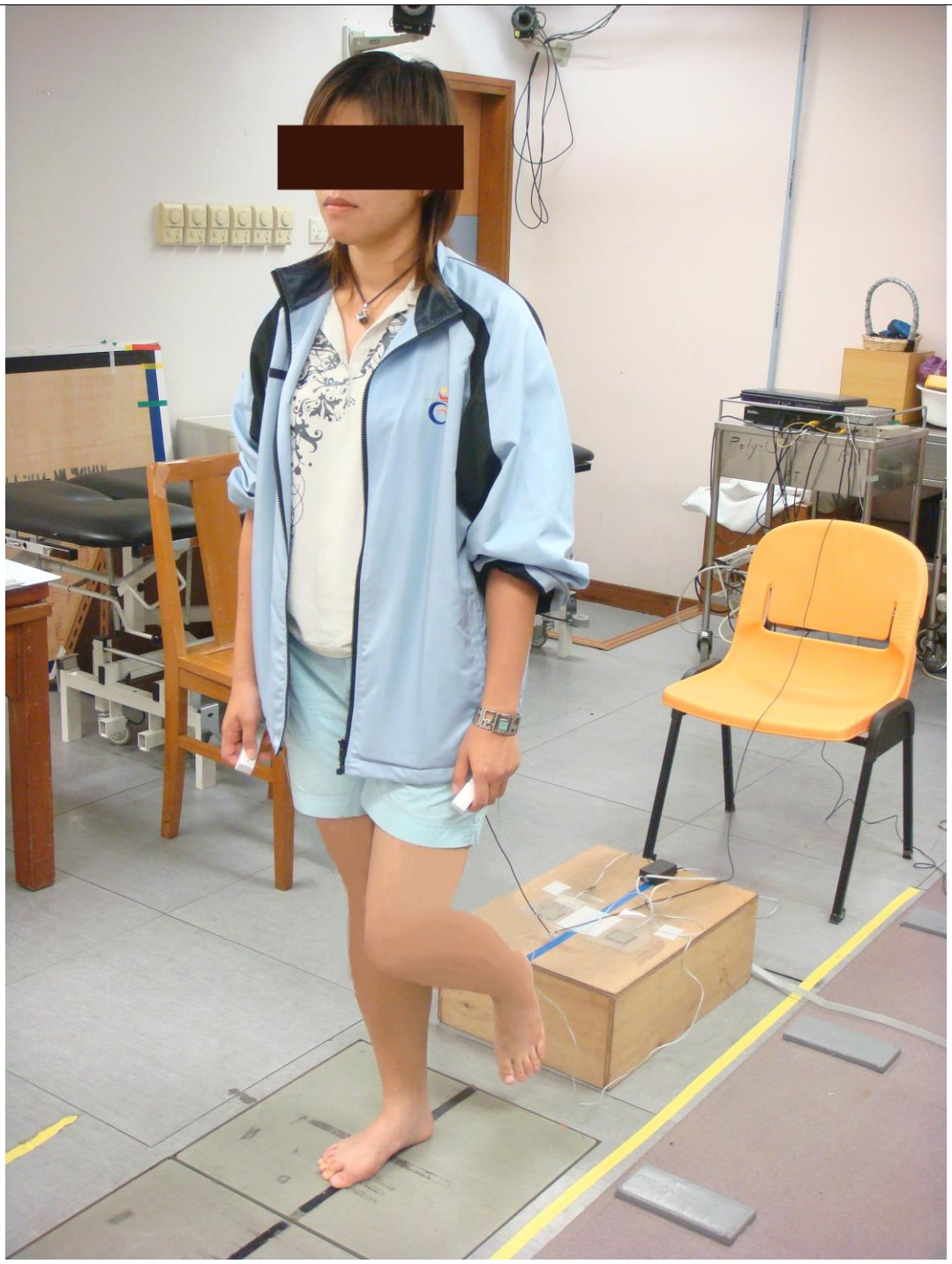

Figure 1. The experimental set up.

Table 1: Demographics of the controls and Tai Chi subjects

Characteristics	Control subjects (n=30)	Tai Chi subjects (n=28)	p-value
Age (years)	72.4±6.1	73.6±4.2	0.369
Height (cm)	154.0±6.6	154.6±8.2	0.757
Weight (kg)	58.5±8.3	55.4±9.9	0.197
Sex (male/female)	7/23	9/19	0.453
MMSE score	26.8±2.1	26.8±2.0	0.919
Physical activity level (n)			0.262
Light ≤4	5	4	
Moderate ≤4–5.5	25	23	
Heavy >5.5	0	1	

Values are mean ± SD

Table 2: Auditory Stroop test under single- and dual-task conditions

	Control subjects (n = 30)			**Tai Chi subjects (n = 28)**			***p*-value**		
	Single-task	**Dual-task**	**% change**	**Single-task**	**Dual- task**	**% change**	**Single-task**	**Dual-task**	**Group x task**
Reaction time (s)	1.04±0.31	1.87±0.48*	80%	0.98±0.35	1.58±0.46*	61%	0.523	0.023#	0.046**
Error rate (%)	16±12	26±15*	63%	6±7	13±12*	117%	0.001#	0.001#	0.112

** indicates a group x task interaction significant at the p<0.05 confidence level in an univariate test.

* indicates a within-group difference when compared with single-task significant at the p<0.05 confidence level.

# indicates a between-group difference significant at the p<0.05 confidence level.

Table 3. Center of pressure changes during single- and dual-task stance

	Control subjects (n = 30)		**Tai Chi subjects (n = 28)**		***p*-value**		
	Single- task	**Dual- task**	**Single- task**	**Dual- task**	**Single-task**	**Dual-task**	**Group x task**
COP path (mm)	289.6±116.3	293.1±74.9	252.8±57.7	258.3±41.8	0.136	0.033#	0.265
COP area (cm^2)	10.6±3.8	11.3±4.9	8.4±2.6	9.0±2.5	0.014#	0.034#	0.200

# indicates a between-group difference significant at the $p<0.05$ confidence level.