AGE (2009) 31:163–170
DOI 10.1007/s11357-009-9094-3

Is Tai Chi Chuan effective in improving lower limb response time to prevent backward falls in the elderly?

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Received: 19 October 2008 / Accepted: 29 March 2009 / Published online: 5 May 2009

Abstract To evaluate the training effect of Tai Chi Chuan (TCC) in postural control and backward fall prevention in the elderly, balance assessment and visually guided lower limb response time were analyzed in a case-control study conducted in a community setting. Thirty-one elderly subjects (mean age: 68.2±6.8 years) participated in the TCC group, 30 community-dwelling elderly subjects with matched age and body composition served as the elderly control group, with 13 young adults (mean age: 27.5±3.8 years) serving as young controls. The TCC group had practiced TCC regularly five times per week, for over 30 min per day for at least 4 years. Lower limb response time were measured using a computerized dance machine that we developed, which contains two blocks during testing: single and dual feet. The motor planning of the latter is more complex than the former. Postural control was assessed by computerized posturography (Smart Balance Master). Compared to the elderly controls, the TCC group demonstrated significantly better balance performance in sway-referenced support, which is more challenging. Moreover, the TCC group had better dual feet response than the elderly controls in the forward–backward, forward–right and forward–left directions. Practicing TCC may improve motor responses and postural control in the elderly, particularly in more challenging situations. Subjects showed better postural responses to unexpected perturbation in the forward–backward and forward–sideways direction than sideways or backward–sideways directions, which may have clinical relevance.

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Keywords Elderly · Tai Chi Chuan · Lower limb response time · Backward fall · Tai Chi

Introduction

Incidental fall is a major cause of morbidity and mortality in the elderly (Wolter and Studenski 1996). Decline in balance control in elderly people leads to impairments in postural stability and dynamic equilibrium, which may result in an increase in incidental falls (Horak et al. 1989; Patla et al. 1990). Fall direction influences the impact location of injury, with sideways falls having the highest risk of hip fracture, and backward falls the highest risk for wrist and vertebral fractures (Sandler and Robinovitch 2001).

Regular physical training has been proposed to enhance functional capacity, and reduce morbidity and mortality for elderly individuals with sedentary lifestyles (Rikli and Jones 1997). For the elderly, some oriental conditioning exercises merit greater attention because of their accessibility and low-cost, and the ease with which they can be accommodated in the community.

Tai Chi Chuan (TCC) is a Chinese conditioning exercise suitable for the elderly and patients with chronic disease. Basic TCC exercise is composed of a series of graceful motions linked together in a continuous sequence so that the body is continuously shifting from one foot to another, with a lower center of gravity. TCC is capable of improving balance, kinesthetic sense and strength, thus minimizing the fear of falling (Jacobson et al. 1997; Tsang et al. 2004). In the Frailty and Injuries Cooperative Studies of Intervention Techniques (FICSIT) study, the risk of multiple incidental falls can be reduced by 47.5% among elderly TCC practitioners (Wolf et al. 1996) compared to the education control group. The same authors also found that TCC improves flexed posture, limitations in trunk rotation and reluctance to engage single leg stance (Wolf et al. 1997a).

Elderly TCC practitioners show better postural control than their sedentary counterparts (Schaller 1996; Tse and Bailey 1992) in simple balance tests (such as duration of single-leg standing with eyes open or closed) and computerized posturography (Jacobson et al. 1997; Wolf et al. 1996; Wong et al. 2001). However, investigators have questioned the validity of using postural sway in computerized posturography to predict dynamic postural control in daily life and in assessing motor response to incidental falls (Lan et al. 2002). Therefore, we have developed a device to measure lower limb response time. The device assesses a participant's response to an environmental stimulus by measuring actual lower limb movement.

Computerized dance machines (CDM; Fig. 1) are popular among young people. A CDM has a platform with four arrows, each representing a direction of up, down, left or right. There are also four stationary arrows that scroll up from the bottom of the screen.

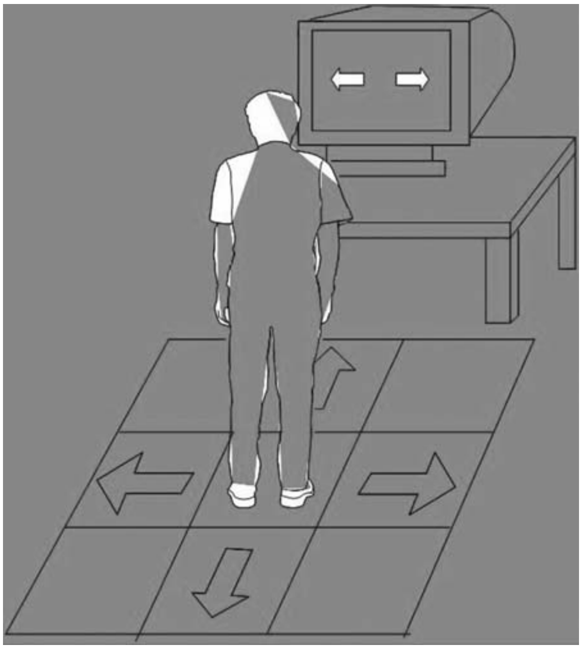

Fig. 1 Computerized dance machine (CDM) and the preparatory posture of the participant

When the scrolling arrows overlap the stationary arrows, the player should hit the corresponding arrow on the platform. In the present study, a CDM was modified to assess lower limb response time. The participant was instructed to stand in the center of the pad as the initial position. When the monitor displayed the arrow(s) randomly, the participant reacts by moving his/her foot (feet) to the corresponding location(s) on the CDM platform as fast as possible. Response latency is defined as the response time from the onset of the visual cue to the accomplishment of foot movement on the platform. Latency comprises the time required for visual perception, motor planning and movement of feet to the target pad. The whole process involves dynamic posture, balance and trunk control. Thus, the CDM device can be used to collect data regarding the response time of trunk and lower limb movements under visual cues.

Our aim was to combine CDM and computerized posturography to assess postural control and dynamic responses to the changing environment. We hypothesized that TCC practitioners would respond better to postural and visual stimuli than their nonpractitioner counterparts, and that TCC may benefit postural control in anterior, posterior, or left–right directions.

Methods

Study participants

The TCC practitioners were recruited from a TCC club and the elderly controls from the volunteers group of Chang Gung Memorial Hospital. All participants were community dwellers and led an active lifestyle. None had a history of incidental falls in the previous 3 months. The TCC participants had been practicing TCC regularly for at least 30 min daily, five times per week for at least 4 years. This study was approved by the Institutional Review Board for Human Subject Research in Chang Gung Memorial Hospital.

All participants were apparently healthy and were examined by the same physician. A medical history was taken and physical examination completed before each participant was enrolled. Participants with a history of significant cardiovascular, pulmonary, metabolic, musculoskeletal (e.g., bone fracture, artificial joint replacement) or neurological disease (e.g., stroke, Parkinson's disease, dementia, poor vision) were excluded. No participants had prior experience in playing the CDM dance game.

Thirty-one TCC practitioners (10 males, 21 females, mean age 68.8±6.8 years), 30 healthy and active non-practitioners (9 males, 21 females, mean age 68.8±5.1 years) and 13 young participants (4 males, 9 females, mean age 27.5±3.8 years) were recruited for this investigation (Table 1).

Instrumentation

Computerized dance machine

The CDM is designed to simulate the conditions in which a subject responds to an external environmental cue and performs a rescue/stepping response to an incidental fall. CDM can measure lower limb response time, but not postural stability. This device was modified from a commercially available product—Dance Dance Revolution (Fig. 1). The CDM comprised a desktop computer and a touch pad platform placed on the floor. Labview-based software (National Instruments, Austin, TX) was employed to control visual cue and data acquisition. The computer screen displayed the visual cues to indicate the direction(s) of lower limb responses. Visual cues were displayed as arrows in sequence. For example, the visual cue of a left arrow indicated that the proper response is to step on the corresponding left arrow on the platform; the visual cue of both left and right arrows instructed the participant to step onto both left and right arrows concurrently. Response time is defined as the latency between onset of the visual cue and stepping on the dance platform. Four sensors were embedded in the touch pad platform in the four directions (anterior, left, posterior and right) to record lower limb responses in each direction. The computer monitor was placed 60 cm in front of the testing participant, and the participant was standing on the center of the touch pad platform.

Computerized posturography

Computerized posturography using the SMART Balance Master (NeuroCom International, Clackamas, OR) was applied to measure postural stability under defined conditions. This device consists of two 9×18-inch forceplates on which participants stand. The two forceplates are supported by four transducers mounted on a supporting center plate. A fifth transducer is bracketed to the center plate directly beneath the pin joint. A visual enclosure, comprising a wall covered with gray-collar aluminum sheet and a small blue dot pattern, enclosed the participant on three sides, and a computer monitor was positioned 60 cm in front of the participant at eye level. The device also comprises an overhead bar with safety harness, and an integrated computer and software system. The sampling rate of the forceplates was 100 Hz.

Procedures

Computerized dance machine

Before receiving each visual cue, the participant was instructed in a preparatory standing posture on the center of the touch pad. The task requires the participants to move their foot (feet) in the instructed direction(s) and to press the pad as fast as possible when the visual cue was displayed. The inter-trial intervals (ITI) varied between 3 and 5 s with a uniform distribution. The response time was defined as the latency from the onset of the visual cue to the

Table 1 Demographic data in the three study groups. *TCC* Tai Chi Chuan

	TCC	Elderly control	Young control	*P*-value	Post-hoc
N	31	30	13		
Gender (M/F)	10/21	9/21	4/9	0.849	
Age (years)[a]	68.2 (6.8)	68.8 (5.1)	27.5 (3.8)	<0.001**	ac, bc
Body weight (kg)[a]	59.0 (7.9)	58.2 (8.8)	59.2 (9.8)	0.905	
Body height (cm)[a]	157.0 (7.2)	158.2 (6.5)	163.5 (8.0)	0.173	

***$P<0.001$

[a] Values expressed as mean (standard deviation); ac: comparing TCC with young control; bc: comparing elderly control with young control

participant stepping on the touch pad. The CDM task was performed in two blocks: (1) single foot testing—the visual cue comprised only one of the four directions, i.e., anterior, left, posterior or right; (2) dual feet testing—the visual cue involved combinations of any two directions, yielding six possible combinations, namely anterior–posterior, left–right, anterior–left, anterior–right, posterior–left, posterior–right. The participants performed the simple tasks followed by the complex tasks.

A total of 50 practice trials were required for each participant to become familiarized with the procedure. During the examination, each participant performed 15 blocks of tests, of which 5 consisted of single foot trials, 5 of dual feet trials, and 5 of mixed (50% single and 50% dual) trials. Each block contained ten visually guided trials on lower limb response time. Blocks containing any inaccurate responses (e.g., missed the correct arrow on the touch pad) were disregarded and the test was repeated to achieve a 100% accuracy rate.

Computerized posturography

Before the test, body height and weight were measured and a harness was secured with straps to an overhead bar to protect the participant in case of a fall. Participants stood in bare feet on the platform with the medial malleolus at the rotation axis, as indicated by a line on the forceplates. The lateral borders of the feet were placed 26.5 cm apart and equidistant from the centerline of the force platform. The feet were pointed slightly outward to permit a comfortable and natural foot placement.

Postural stability was sequentially assessed under the following conditions: (1) eyes open and fixed support (EO); (2) eyes closed and fixed support (EC); (3) sway-referenced vision and fixed support (SV); (4) eyes open and sway-referenced support (SS); (5) eyes closed and sway-referenced support (ECSS); and (6) sway-referenced vision and support (SVSS). Two trials of EO and EC, and three trials for the other conditions were performed. Each trial lasted 20 s and the results from repetitions within each condition were averaged.

Statistics

Chi–square tests were applied to compare the gender distribution among the three study groups; namely the TCC, elderly control, and young control groups. ANOVA was adopted to compare differences in age, body weight and body height among the three study groups. In the single foot CDM test, repeated-measures ANOVA (two groups × four directions) was used to compare response time between the two elderly groups (TCC and control groups). Similarly, in the dual feet CDM test, repeated-measures ANOVA (two elderly groups × six directions) was applied. Also, repeated-measures ANOVA (two elderly groups × six conditions) was used to contrast the maximal stability, ankle strategy and center of pressure (COP) velocity between the two elderly groups. Data are presented as mean (standard deviation). Statistical significance was set at $P<0.05$.

Results

Demographic data

Table 1 lists the demographic data of the three groups. The young control group was younger than the TCC or elder control group ($P<.01$). No age difference existed between the TCC and elder control group. All three groups contained no significant differences in gender distribution, body weight or height.

Simple and dual feet response time tests

Substantial differences between the two elderly groups in favor of the TCC group were observed in the dual feet ($F=5.78$, $P<.0.02$), but not in the single foot ($F=1.86$, $P>.05$) results (Fig. 2). Regarding the response time to different directions, significant differences between directions were observed in the single foot ($F=44.0$, $P<.001$) as well as in dual feet tests ($F=102.4$, $P<.01$) in data pooled from the two study groups. Considerable interaction effects between the two elderly groups and response time to different directions were demonstrated in the dual feet response time test ($F=4.26$, $P=0.001$), especially in the forward–backward (FB), forward–right (FR), and forward–left (FL) tests but not in the left–right (LR), backward–right (BR) or backward–left (BL) test. Namely, the effect that the response time of the TCC group is shorter than that of the control group is more prominent in the directions FB, FR and FL. In summary, the improvement of complex response time to situations involving bilateral lower limbs in TCC practitioners varies with directionality.

Balance in computerized posturography

The TCC group was significantly better than the elderly control group in the performance of maximal stability ($F=14.3$, $P<.001$), but not in ankle strategy ($F=1.07$) or center of gravity velocity ($F=3.38$) (Fig. 3). Performance differed significantly among the six balance conditions in maximal stability ($F=362.5$, $P\leq0.001$), ankle strategy ($F=238.9$, $P\leq0.001$) and center of gravity velocity ($F=55.0$, $P\leq0.001$) in both the elderly groups; i.e., performance in relatively easy situations is better than that in challenging ones. The interaction effect between study groups and the six balance conditions was apparent in maximal stability ($F=6.09$, $P<.0.001$) and center of gravity velocity ($F=2.72$, $P<0.02$), but not in ankle strategy ($F=1.36$; Fig. 3), indicating that the contrast of training effect was more significant in more challenging conditions. In specific challenging conditions, the TCC group demonstrated better maximal stability and center of gravity velocity than the elderly control, including eyes open swayed support (EOSS), eyes closed with swayed support (ECSS), and swayed vision reference and swayed support (SVSS) ($P<0.05$).

Discussion

In this investigation, deterioration of balance was significantly affected by aging in dynamic balance in more sensory-deprived conditions such as EOSS, ECSS, and SVSS, but not significantly affected in static stance such as EO, EC and SV status. The practice of TCC may attenuate this age-related decline in balance. Lower limb response time and computerized posturography from the TCC group showed better performance than their age-matched counterparts in more challenging (dynamic balance, dual feet responses) conditions. These findings indicate that practicing TCC may improve daily function in more challenging tasks involving complex motor planning and coordination. For example, when walking across a street, the elderly need to use visual and other sensory cues to plan and execute trunk and limbs movements in response to the changing environment.

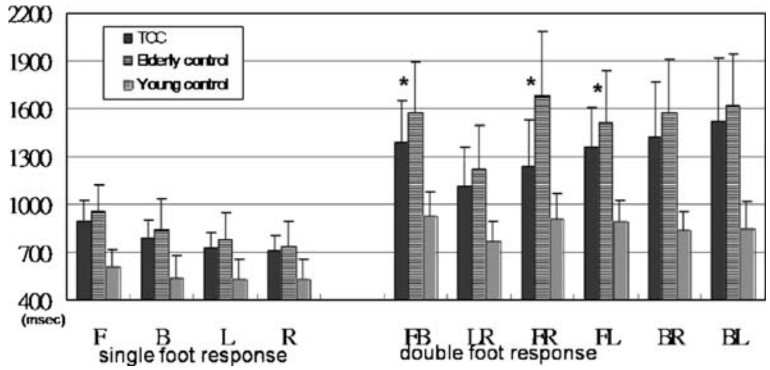

Fig. 2 Comparison of response time (ms) in single and dual feet dance tests in the three groups. *TCC* Tai Chi Chuan, *F* forward, *B* backward, *L* left, *R* right, *FB* forward–backward, *LR* left–right, *FR* forward–right, *FL* forward–left, *BR* backward–right, *BL* backward–left. * $P<0.05$, TCC vs elderly groups. Values are expressed as mean ± standard deviation

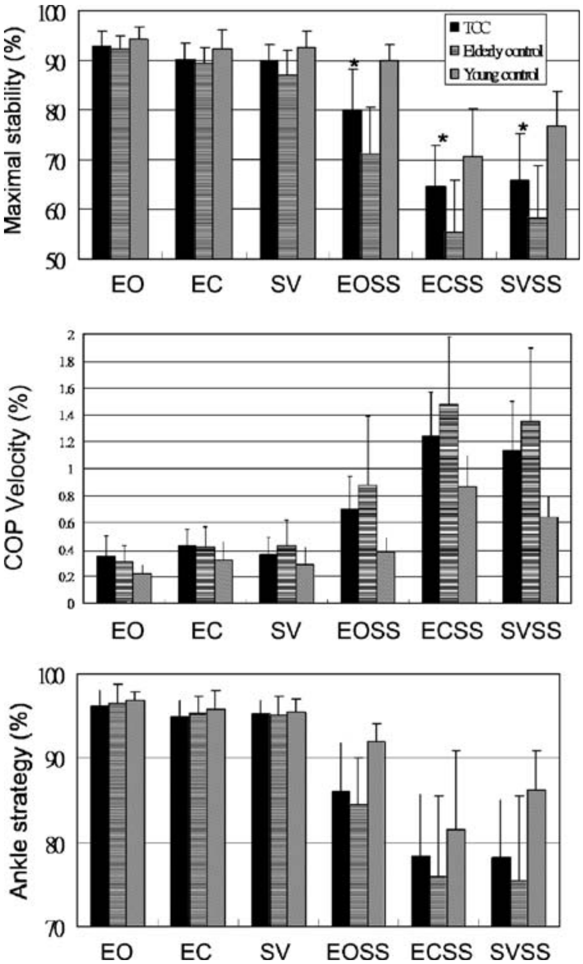

Fig. 3 Maximal stability, center of pressure (COP) velocity and ankle strategy in the three study groups. *EO* Eyes open, *EC* eyes closed, *SV* sway-referenced vision and fixed support, *EOSS* eyes opened and sway-referenced support, *ECSS* eye closed and sway-referenced support, *SVSS* sway-referenced vision and support. Values are expressed as mean ± standard deviation

The development of an objective assessment tool for balance and motor response enables effective evaluation of the risk of incidental falls and the effectiveness of conditioning exercise. Since both the dual feet lower limb response time and balance are useful in assessing improvement after TCC training, such assessments are sensitive enough to document the aging effect as well as the effectiveness of TCC.

It has been reported that limits of stability can be used as a significant predictor of performance in functional activities, such as climbing a flight of 27 stairs, crossing a street, and getting onto a bus (Topp et al. 1998). Also, limits of stability were reported to play a significant role in indicating susceptibility to falls (Girardi et al. 2001). In the FICSIT study, TCC benefited elderly practitioners by maintaining balance gains following a 3-month balance training course, and established a trend toward further improvement in balance (Wolfson et al. 1996). Tsang and Hui-Chan (2003) also confirmed that long-term TCC practitioners achieved greater limits of stability. In another FICSIT study in Atlanta, although 15 weeks of TCC training did not improve measures of postural stability, it reduced the fear of falling (Wolf et al. 1997b). In the present investigation, we found that significant improvement of postural control in the TCC group was noted only on counter-active responses to unexpected perturbation with automatic motor action in forward anticipatory perturbation, but not in backward perturbation (Fig. 2). The finding may be related to the fundamental posture. The movements performed in TCC are mainly forward and sideways, and less in a backward direction. This observation, which implies that the effectiveness of exercise training is more context-specific, has not been previously reported in the literature.

TCC practice requires repeated single leg stands with a slow weight shift in various postures. Theoretically, the exercise helps to improve participant's balance and postural control. Also, the practice of TCC involves precise control of the weight shift between double and single leg stance in a smooth and coordinated manner. This investigation found that TCC practitioners showed a better response time in more complex situations involving bilateral lower limbs. Moreover, this improvement depends on the direction. Significant counteractive responses were found in unexpected perturbation in the F–B, R–F and L–F directions, but not in the L–R, RB or LB directions. The effectiveness of TCC practice may be attributable to the integrated movements of trunk, limbs and total body in a coordinated manner. Nonetheless, it is more focused on forward movement training. An advanced training program for TCC practitioners—push-hands (Tuishou)—may be helpful in improving backward balance. During push-hands exercise, two participants gently push each other with one or two hands, which consists of repeated motions of "forward shifting—push—backward shifting—trunk rotation" (Hong et al. 2000). In the whole set of Yang's style (108 forms), each complete set of practice takes 24 min. However, there are only a few backward-shifting postures (approx. 2 min) in the whole practice set (Chiu and Mao 2006). Furthermore, simplified TCC programs lack the incorporation of adequate backwards-related postures. This may explain why TCC practitioners display inadequate backward–sideways lower limb responses. Therefore, TCC involving some backward movements may improve lower limb response action time in the backward direction.

The results may provide new insights into the mechanism of the fall prevention effect of TCC practice. The data demonstrate that the effects come not only from improved muscle strength, kinesthetic sense, body flexibility, and motor control of upper extremities (Klein and Adams 2004; Nnodim et al. 2006; Pei et al. 2008; Tsang and Hui-Chan 2006), but also from the improvement of motor programming of lower extremities to make a prompt response to environmental stimuli. However, TCC practice displayed insufficient training effect in the backward direction. Therefore, we propose adding more backward movements in TCC to shorten the backward response time, thereby possibly decreasing fall risk.

Conclusion

This investigation proved that TCC may improve motor response and postural balance in the elderly, particularly in more challenging conditions. Postural responses to unexpected perturbation were better in the forward–backward and forward–sideways directions than sideways or backward–sideways directions, which may have clinical relevance.

Acknowledgments The authors would like to thank the National Science Council of Taiwan, R.O.C. for financially supporting this research under NSC92-2314-B-182A-029. We are grateful to have the enthusiastic participation of the participants. Katie P. Wu is appreciated for her editorial assistance.

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