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Biomechanical characteristics of stepping in older Tai Chi practitioners

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ABSTRACT

This study compared the biomechanical characteristics of stepping in 10 older (aged 55+ years) Tai Chi (TC) practitioners and 10 age-matched non-TC (NTC) controls. Subjects were asked to take a step on an auditory cue as fast as possible, in the forward and backward directions, and with and without mental distractions, respectively. Stepping characteristics included step initiation time, preparation time for foot off, foot contact time, and step length and width. The results showed that both groups had similar step initiation time, step length and forward step width ($p > 0.466$). Although mental distraction significantly delayed step initiation time and foot contact time, and shortened step length in both groups ($p < 0.003$), TC practitioners had significantly shorter preparation and foot contact time, and wider backward step width than controls regardless of mental distraction ($p < 0.024$). These group differences are in favor of TC practitioners in situations of postural recovery from potential falls, even with mental distractions, and may explain the positive effect of TC practice on fall reduction in older adults.

1. Introduction

The growing body of scientific studies on Tai Chi (TC), a traditional Chinese martial art, has shown that long-term practice of TC by older adults can lead to significant reduction in accidental falls [1]. As the older adult population increases rapidly and fall incidents increase with advancing age, TC has gained popularity among older adults as a therapeutic exercise to improve postural balance and prevent falls.

The mechanism by which TC prevents falls is still unclear. Most falls occur during ambulation [2] and involve taking one or multiple steps in the falling direction prior to the fall occurrence [3,4]. These pre-fall steps, called protective voluntary stepping, are critical for determining whether a person is going to recover from an impending fall. A faster stepping response to a trigger such as a trip or slip allows people to catch the falling body sooner than a slower stepping response and is shown to be associated with forward trip fall frequencies in older adults [5]. A longer and/or wider step in the falling direction provides a wider base of support and has also shown to be a significant predictor of frequent falls [6]. Moreover, studies comparing the protective stepping characteristics of older adults and young adults have found significantly more frequent steps and significantly shorter and earlier steps in the older population [3,7,8].

Since TC practice can effectively reduce fall incidents in older adults and protective voluntary stepping is associated with falls, it is logical to postulate that TC practitioners may step faster and better than their counterparts. To date, there are limited studies investigating the stepping characteristics of TC practitioners. Nnodim et al. compared the effect of a 10-week TC intervention to that of a dynamic balance and stepping exercise in older adults [9]. The authors only reported the relative changes in stepping between the two interventions. Hass et al. investigated the center of pressure (COP) trajectory changes of gait initiation in older adults after 48 weeks of TC practice [10]. The authors reported an increased posterior displacement of the COP in preparation for foot off post training, which may lead to a larger forward momentum and a potentially faster step. In addition, a few other studies have reported a positive TC training effect in recovery kinematics from a slip during walking [11], and in rhythmic forward–backward weight-shift [12]. All these studies support that TC practice may lead to changes in stepping characteristics that are critical for fall prevention.

Moreover, studies show that people are at a higher risk of falls when they are multitasking or being mentally distracted [13]. Yet, few studies have investigated the biomechanical characteristics of stepping under mental distractions. One study by Melzer and Oddsson compared the temporal characteristics of step initiation with and without distractions and found that older adults had a substantial increase in the initiation phase with distraction compared to the young [14]. However, there is growing body of studies reporting positive outcomes of mind/body exercises on motor function and performance [15], and on standing balance in older adults [16]. Since TC practice involves the mind and the body, it is likely that TC practitioners are less affected by mental distractions when taking a step.

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The purpose of this study was to investigate and compare the biomechanical characteristics of forward and backward stepping in older TC practitioners and age-matched controls in response to an auditory cue with and without mental distractions. It was hypothesized that long-term TC practitioners would step better in terms of timing and stability, either without or with mental distractions.

2. Method

2.1. Subjects

The study included community-dwelling older adults aged 55 years and older. They were all physically fit, functionally independent, and had no neural, muscular, or cerebrovascular diseases likely to affect balance. They were excluded if they were taking centrally active medications or alcohol regularly. The TC practitioners were required to have practiced TC on a regular basis for more than two years, and the controls had not practiced TC at all.

All subjects were voluntarily recruited in response to advertisements posted at area information bulletin boards. Upon enrollment, subjects were asked to sign the informed consent approved by the Institutional Review Board of the University of Vermont.

2.2. Instrumentation and protocol

Two biomechanical force plates (Advanced Mechanical Technologies, Watertown MA) were used. Subjects were asked to stand on one force plate with a standardized foot position (i.e., heels 10 cm apart and toes 15° out), hands behind the back, and eyes looking straight ahead. Subjects were given an auditory cue at random times, and were asked to take a step as quickly as possible with their dominant leg onto the second force plate. The step length and width were not restricted. Subjects were asked to take a forward step first, and then a backward step, three times each. The forward and backward stepping trials were repeated later with a mental distraction. Specifically, prior to the auditory cue, subjects were given a random number between 10 and 30 and asked to keep adding by seven. They were instructed to say the numbers out loud while listening to the auditory cue and then taking a step as quickly as possible. This instruction ensured that subjects gave top priority to the stepping task and that the step timing reflected the subjects' best possible ability. Breaks were allowed between each test condition. Signals from the force plates were collected by a personal computer with a sampling frequency of 1000 Hz for 11 s starting 3 s prior to the auditory cue.

In addition, subjects' demographic information was taken. Vibration perception threshold (VPT) and tactile acuity threshold (TAT) were assessed at four different sites (hallux, first and fifth metatarsophalangeal joints, and heel) under each foot following the standard procedures described by Pham [17]. Plantar pressure sensation plays a role in compensatory stepping [18] and could be affected by regular TC practice [19].

2.3. Data processing and analysis

The following biomechanical characteristics of the stepping task were computed from the force plate measures: temporal features including the step initiation time, preparation time for foot off, and contact time of the stepping foot (see Fig. 1a); and spatial features including step length and step width (see Fig. 1b). All computations were done in Matlab©. Each variable was visually inspected during the computation to ensure accuracy.

The procedures for computing the temporal features were similar to those reported by Melzer and Oddsson [14]. Specifically, the step initiation time was determined as the time when the medial–lateral (ML) foot COP was 10% of the peak shift towards the stepping foot after the auditory cue. The preparation time for foot off was defined as the time from step initiation to foot off which was when the vertical ground reaction force (GRF) of the stance foot was at its downward maximum. Lastly, the foot contact time was determined as the time when the vertical GRF of the step foot was at 10% of the downward maximum.

The step length and width were determined from the anterior–posterior (AP) and ML COP of both stance foot and step foot at the time when the vertical GRF of both feet was equal (or foot loading time, see Fig. 1a). Step length (or width) was the distance between the stance foot AP (or ML) COP and the step foot AP (or ML) COP at foot loading. Both step length and step width were normalized by subject's height.

The primary analysis involved the repeated measures multivariate analysis of variance (MANOVA) with group (TC and non-TC (NTC)) as the between subject variable and mental distraction (no mental distraction (nMD) and mental distraction (MD)) and step direction (forward and backward) as the within subject variables. If significant interactions were found with group, separate repeated measures ANOVA was done for each direction with group as the between subject variable and mental distraction as the within subject variable. Again, if significant group × distraction was found, two-tailed student *t*-test was done to compare differences between groups or between mental distraction conditions. In addition, subject characteristics and within-subject variation in step length and width (defined as the standard deviation of the three trials of each subject relative to their mean value) were compared between groups using student *t*-test. Pearson correlation coefficient (cc) was computed to examine the trial effect of step length and width. A significant difference was set at a *p*-value of 0.05 for all analyses. All analyses were conducted using SPSS (SPSS Inc., Chicago, IL).

3. Results

3.1. Subject information

A total of 20 subjects (six males) participated in the study, with a mean age of 67 ± 10 years. There was no significant group difference in all subject's characteristics (see Table 1) except for TC practice experience. TC practitioners had practiced TC for an average of 18 years, with a range from 2 to 38 years. The frequency of TC practice ranged from three to seven days/week, a minimum of 1 h each time. The most common form of TC was the long-form Yang style. Also, subjects in both groups participated in other forms of physical exercise, mostly in the form of walking, and weight training. The frequency of other exercises was marginally higher in NTC group than in TC group ($p = 0.069$). In addition, all subjects had no self-reported fear of falling or lower extremity weakness.

3.2. Temporal characteristics of stepping

3.2.1. Step initiation time

There were no significant group × distraction or group × direction interactions ($F < 0.066$, $p > 0.801$), and no significant main effect for direction ($F = 1.7780.066$, $p = 0.205$) or group

Table 1
Means and standard deviations of subject characteristics by groups.

Variables		TC	NTC	*p*-value
N (males)		10 (4)	10 (2)	
Age (year)		67 ± 10	67 ± 12	0.924
Body height (cm)		169 ± 11	163 ± 3	0.144
Body weight (kg)		73 ± 16	68 ± 7	0.362
TC practice (year)		18 ± 14	0	0.003
NTC exercise[a] (day/week)		3.6 ± 1.9	5.6 ± 2.7	0.069
Type of NTC exercise		Walk, bike, weight, yoga, pilate	Walk, weight, dance, swim, body combat	
Tactile acuity threshold (range: 1.65–6.65, 20 intervals)	Hallux	$3.9 \pm .6$	$4.1 \pm .3$	0.427
	First MTP	$4.4 \pm .7$	4.6 ± 1.2	0.716
	Fifth MTP	$4.0 \pm .5$	$4.3 \pm .2$	0.097
	Heel	$4.4 \pm .5$	$4.4 \pm .1$	0.883
Vibration perception threshold (range: 0–50 V)	Hallux	15.4 ± 11.7	9.1 ± 1.8	0.147
	First MTP	12.6 ± 6.4	8.9 ± 3.7	0.178
	Fifth MTP	10.9 ± 7.5	7.1 ± 2.7	0.175
	Heel	12.7 ± 10.5	8.4 ± 3.3	0.258

[a] Lasting 30 min or longer each time.

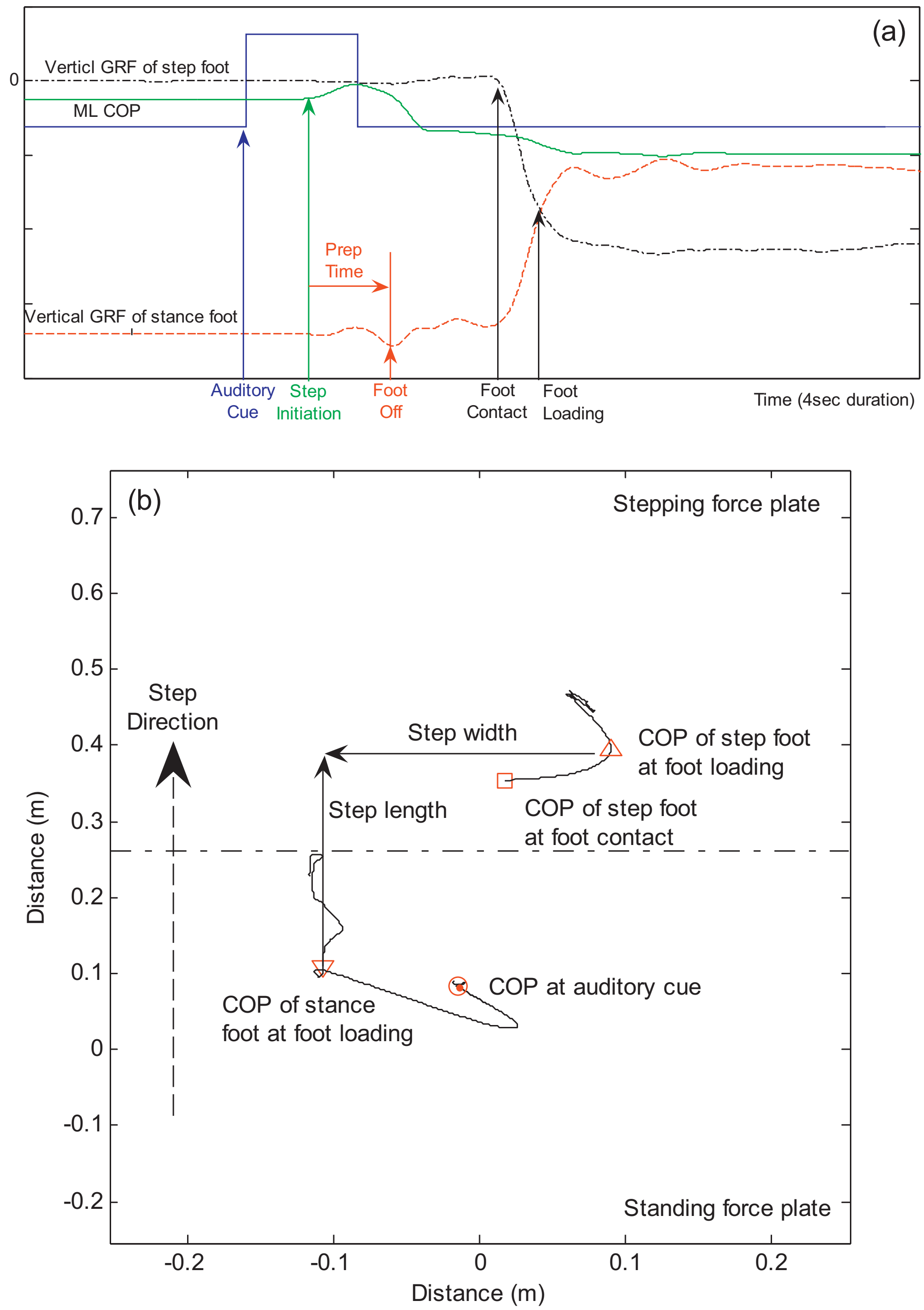

Fig. 1. Definition of the biomechanical variables for stepping. (a) Illustration of step initiation time, preparation time for foot off, foot contact time and foot loading time. The timing of the auditory cue is also shown. ML COP – medial–lateral center of pressure; GRF – ground reaction force. (b) Illustration of step length and step width. The solid lines are the COP trajectories of the stance foot from 3 s prior to auditory cue to 1 s post foot loading, and of the step foot from foot contact to 1 s post foot loading, respectively. The location of the COP at auditory cue (circle), foot contact (square), and foot loading (triangles) are also shown.

($F = 0.111$, $p = 0.745$). However, there was a significant main effect for distraction ($F = 74.074$, $p < 0.001$). Both groups showed a significantly longer step initiation time with distraction than without (see Fig. 2a).

3.2.2. Step preparation time

There were no significant group × distraction or group × direction interactions ($F < 1.009$, $p > 0.334$), and no significant main effect for distraction ($F = 0.019$, $p = 0.893$) or direction ($F = 0.052$, $p = 0.823$). However, there was a significant group effect ($F = 11.065$, $p = 0.005$). Subjects in the NTC group had significantly longer preparation time than those in the TC group for both step directions, regardless of distraction (Fig. 2b).

3.2.3. Foot contact time

There were no significant group × distraction or group × direction interactions ($F < 0.831$, $p > 0.379$), and no significant main effect for direction ($F = 0.286$, $p = 0.602$). However, there were significant main effects for group ($F = 7.784$, $p = 0.015$) and distraction ($F = 13.600$, $p = 0.003$). Subjects in both groups had

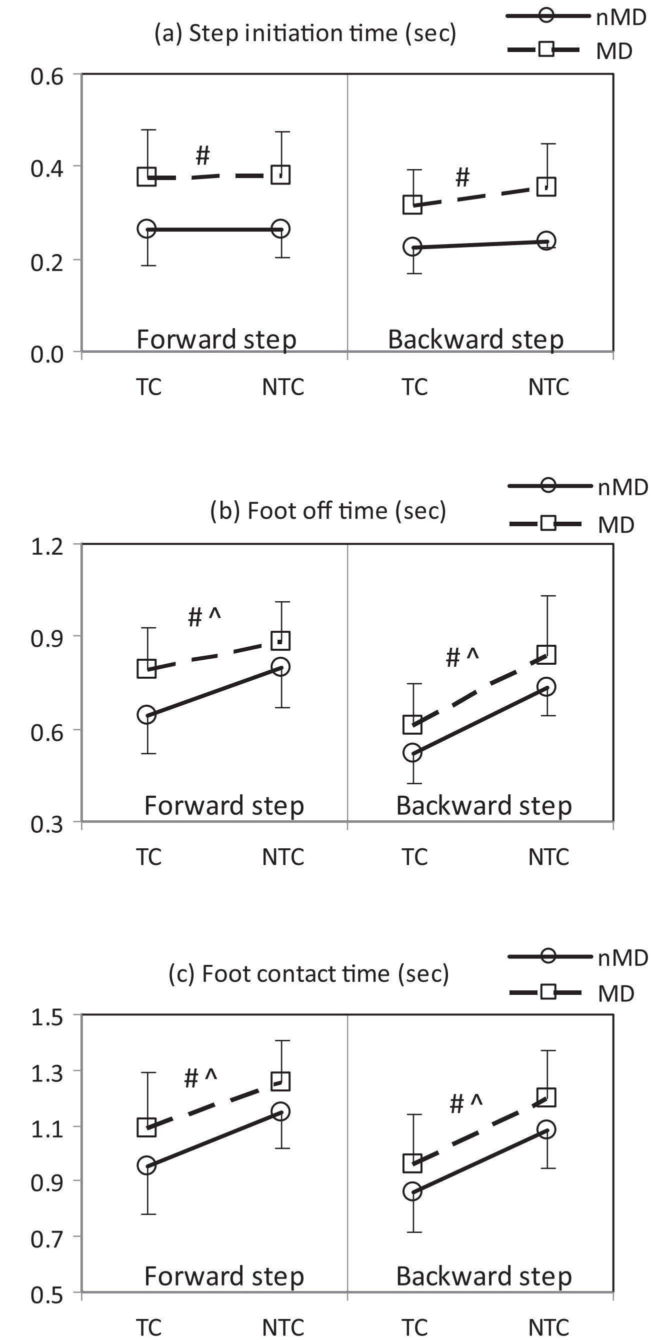

Fig. 2. Means and standard deviations of (a) step initiation time; (b) step preparation time; and (c) foot contact time, in both mental distraction conditions (MD and nMD) and step directions (forward and backward). Symbol ∧ indicates a significant group effect, and symbol # indicates a significant distraction effect.

significantly longer foot contact time with distraction than without, and subjects in the NTC group had significantly longer foot contact time than those in the TC group (Fig. 2c).

3.3. Spatial characteristics of stepping

3.3.1. Step length

There were no significant interactions between group, direction or distraction ($F < 0.362$, $p > 0.555$) or main group effect ($F = 0.323$, $p = 0.577$). However, a significant main effect was found for direction ($F = 61.216$, $p < 0.000$) and distraction ($F = 5.071$, $p = 0.037$), with a significantly shorter step length in backward step than in forward step, and with distraction compared to without (see Fig. 3a). Within-subject variation was not significantly different between groups (6.2 ± 3.4% TC vs. 6.6 ± 3.3% NTC, $p = 0.666$), and Pearson correlation showed no significant trial effect (cc = 0.087, $p = 0.248$).

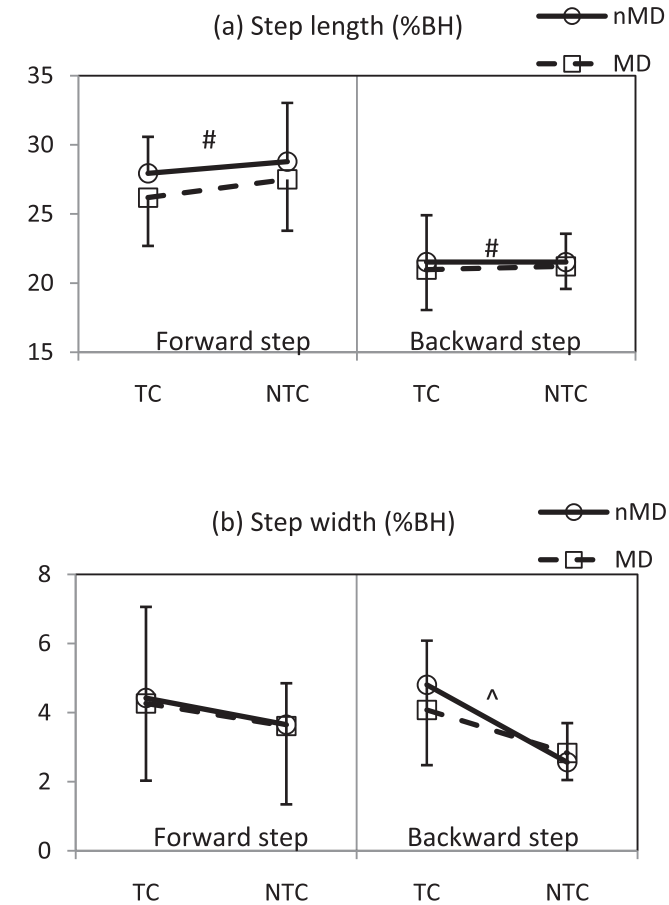

Fig. 3. Means and standard deviations of (a) step length; and (b) step width, in both mental distraction (MD and nMD) and step directions (forward and backward). Symbol ∧ indicates a significant group effect, and symbol # indicates a significant distraction effect.

3.3.2. Step width

There were marginally significant interactions between group, direction and distraction ($F > 3.702$, $p < 0.070$). Separate repeated measures ANOVA for each direction indicated a significant group effect ($F = 30.332$, $p = 0.024$) in backward stepping only, with a significantly wider step in the TC group compared to the NTC group (see Fig. 3b). Within-subject variation was not significantly different between groups (25.4 ± 15.9% TC vs. 28.9 ± 21.3% NTC, $p = 0.517$), and Pearson correlation showed no significant trial effect (cc = 0.060, $p = 0.422$).

4. Discussion

This study is aimed at comparing the biomechanical characteristics of forward and backward stepping in older TC practitioners and age-matched controls with and without mental distractions. Overall, the results show that mental distraction slows down the step initiation and foot contact time, and decreases step length in both TC and NTC practitioners. However, compared to NTC practitioners, long-term TC practitioners have less preparation time to lift up the stepping foot, are faster to land the stepping foot, and have a wider backward step regardless of mental distractions.

These group differences support our hypotheses that long-term TC practitioners step better than their counterparts in terms of timing and stability, even with mental distractions.

The faster stepping time in TC practitioners than their counterparts is in agreement with the study by Voukelatos et al. who reported a significant improvement in choice stepping reaction time in older adults who received 16 weeks of TC training as compared to baseline and controls [20]. We speculate that the mechanism for the faster stepping time in TC practitioners is partly due to the effect of TC practice on sensory-motor integration and cortical plasticity. Numerous studies have shown that long-term TC practice leads to better performance on sensory organization tests than controls [12]. Also, Kerr et al. [21] have shown that long-term TC practitioners have better tactile acuity in the fingers than controls, although TC practice does not engage in direct tactile stimulation in the hands. These studies provide evidence that TC practice may lead to cortical plasticity that enhances sensory acuity and central processing, which is shown to be associated with the timing of anticipatory postural adjustment [22].

In addition, our findings further indicate that the faster stepping time in TC practitioners is primarily due to the shorter preparation time to lift the stepping leg. Rogers et al. found that the step preparation time can be improved in older adults following a step training [23]. Since TC exercise involves frequent stepping in multiple directions, it is likely that long-term TC practice has the similar effect as the step training shown in the study by Rogers et al. It should be pointed out that TC practice involves slow stepping while the step training in Rogers et al. study involves fast stepping. It is possible that these two different training paradigms have different mechanisms in changing the step preparation time, although the end result is similar.

A faster stepping time is biomechanically and functionally important to reduce the likelihood of falling upon postural perturbations. Pavol et al. found that the delayed support limb loading of the protective stepping was significantly associated with falls after being tripped during walking [13]. Medell and Alexander also found a significant association between step time and other measures of balance and fall risk [24]. The faster step time in TC practitioners may be one of the contributing factors for their reduced incidents of falls.

Similar to step time, step length and width are also important factors for successful fall recovery. Our findings indicate that subjects in both groups have similar step length despite the faster stepping time in TC group. The similar step length is likely due to the similarity in their body size. Moreover, we found significantly wider backward steps in TC practitioners. This group difference is particularly interesting and clinically important since backward falls account for 25% of falls in older adults [25] and often lead to wrist and hip fractures [26,27]. Medell and Alexander reported that the mean step size of older adults at risk for falls is 30% smaller than those not at risk for falls [24]. The group difference in backward step width in our study is 47% and 30% with and without distraction, respectively. These significant reductions may put NTC practitioners at an increased risk for backward falls.

Mental distraction is common in daily activities, and has a direct impact on postural stability and balance in older adults. Shumway-Cook et al. found that the simultaneous performance of an additional task increased the time taken to complete a functional balance test, with the greatest effect in the older adults with a history of falls [28]. Coppin et al. also found a significant reduction in gait speed among older adults when being distracted by another task [29]. Similarly, the findings in this study show that both TC and NTC practitioners are affected by the presence of mental distraction for their stepping performance. Nevertheless, TC practitioners complete their step faster than their counterparts under distraction. This is in contrast to the study by Melzer et al. who found no difference in stepping time between older adults with and without regular exercises under dual task conditions [30]. This difference is probably due to the fact that TC is a mind–body exercise that has a potential to improve mental concentration and processing capacity.

Although this study is a cross-sectional design, the subjects in both groups are comparable in many ways other than TC practice. They are all physically active and fit, and free of neuromuscular disorders. They are similar in age, other demographic measures, and peripheral somatosensory thresholds. These group similarities further narrow the range of other confounding factors competing for the explanation of the group differences.

5. Conclusions

This study compared the differences between older TC and NTC practitioners in step initiation characteristics with and without mental distraction. It was found that mental distraction significantly delayed step times and shortened step length in both groups. However, TC practitioners had a shorter preparation time to lift the stepping foot, a shorter step foot contact time, and a wider backward step width than NTC practitioners regardless of mental distraction. These group differences are in favor of the TC practitioners in situations of postural recovery from potential falls, even with mental distractions, and may explain the positive effect of TC practice on fall reduction in older adults.

Conflict of Interest

The author testifies that there was no conflict of interest.

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References

[1] Li F, Harmer P, Fisher KJ, McAuley E, Chaumeton N, Eckstrom E, et al. Tai Chi and fall reductions in older adults: a randomized controlled trial. The Journals of Gerontology Series A Biological Sciences and Medical Sciences 2005;60(2):187–94.
[2] Berg WP, Alessio HM, Mills EM, Tong C. Circumstances and consequences of falls in independent community-dwelling older adults. Age Ageing 1997;26(4):261–8.
[3] Luchies C, Alexander NB, Schultz A, Ashton-Miller J. Stepping responses of young and old adults to postural disturbances: kinematics. Journal of American Geriatrics Society 1994;4(5):506–12.
[4] Pai YC, Rogers MW, Patton J, Cain TD, Hanke TA. Static versus dynamic predictions of protective stepping following waist-pull perturbations in young and older adults. Journal of Biomechanics 1998;31(12):1111–8.
[5] Smeesters C, Hayes WC, McMahon TA. The threshold trip duration for which recovery is no longer possible is associated with strength and reaction time. Journal of Biomechanics 2001;34(5):589–95.
[6] Cho BL, Scarpace D, Alexander NB. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. Journal of the American Geriatrics Society 2004;52(7):1168–73.
[7] McIlroy W, Maki B. Age-related changes in compensatory stepping in response to unpredictable perturbations. Journal of Gerontology Medical Science 1996;51A(6):M289–96.
[8] Jensen JL, Brown LA, Woollacott MH. Compensatory stepping: the biomechanics of a preferred response among older adults. Experimental Aging Research 2001;27(4):361–76.
[9] Nnodim JO, Strasburg D, Nabozny M, Nyquist L, Galecki A, Chen S, et al. Dynamic balance and stepping versus Tai Chi training to improve balance and stepping in at-risk older adults. Journal of the American Geriatrics Society 2006;54(12):1825–31.
[10] Hass C, Gregor R, Waddell D, Oliver A, Smith D, Fleming R, et al. The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. Archives of Physical Medicine and Rehabilitation 2004;85(10):1593–8.

[11] Gatts SK, Woollacott MH. How Tai Chi improves balance: biomechanics of recovery to a walking slip in impaired seniors. Gait & Posture 2007;25(2): 205–14.
[12] Wong AM, Lin YC, Chou SW, Tang FT, Wong PY. Coordination exercise and postural stability in elderly people: effect of Tai Chi Chuan. Archives of Physical Medicine and Rehabilitation 2001;82(5):608–12.
[13] Pavol MJ, Owings TM, Foley KT, Grabiner MD. Mechanisms leading to a fall from an induced trip in healthy older adults. Journals of Gerontology Series A Biological Sciences and Medical Sciences 2001;56(7):M428–37.
[14] Melzer I, Oddsson LIE. The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. Journal of the American Geriatrics Society 2004;52(8):1255–62.
[15] Taktek K. The effects of mental imagery on the acquisition of motor skills and performance: a literature review with theoretical implications. Journal of Mental Imagery 2004;28(1/2):79–114.
[16] Hamel MF, Lajoie Y. Mental imagery. effects on static balance and attentional demands of the elderly. Aging Clinical and Experimental Research 2005;17(3):223–8.
[17] Pham H, Armstrong DG, Harvey C, Harkless LB, Giurini JM, Veves A, et al. Screening techniques to identify people at high risk for diabetic foot ulceration: a prospective multicenter trial. Diabetes Care 2000;23(5):606–11.
[18] Perry SD, McIlroy WE, Maki BE. The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. Brain Research 2000;877(2):401–6.
[19] Richerson S, Rosendale K. Does Tai Chi improve plantar sensory ability?. A pilot study. Diabetes Technology & Therapeutics 2007;9(3):276–86.
[20] Voukelatos A, Cumming RG, Lord SR, Rissel C. A randomized, controlled trial of Tai Chi for the prevention of falls: the central Sydney Tai Chi trial. Journal of the American Geriatrics Society 2007;55(8):1185–91.
[21] Kerr CE, Shaw JR, Wasserman RH, Chen VW, Kanojia A, Bayer T, et al. Tactile acuity in experienced Tai Chi practitioners: evidence for use dependent plasticity as an effect of sensory-attentional training. Experimental Brain Research 2008;188(2):317–22.
[22] Sparto P, Aizenstein H, Vanswearingen J, Rosano C, Perera S, Studenski S, et al. Delays in auditory-cued step initiation are related to increased volume of white matter hyperintensities in older adults. Experimental Brain Research 2008;188(4):633–40.
[23] Rogers MW, Johnson ME, Martinez KM, Mille M-L, Hedman LD. Step training improves the speed of voluntary step initiation in aging. Journals of Gerontology Series A Biological Sciences and Medical Sciences 2003;58(1):M46–51.
[24] Medell JL, Alexander NB. A clinical measure of maximal and rapid stepping in older women. Journals of Gerontology Series A Biological Sciences and Medical Sciences 2000;55(8):M429–33.
[25] Hausdorff J, Edelberg H, Mitchell S, Goldberger A, Wei J. Increased gait unsteadiness in community-dwelling elderly fallers. Archives of Physical Medicine and Rehabilitation 1997;78(3):278–83.
[26] Palvanen M, Kannus P, Parkkari J, Pitkajarvi T, Pasanen M, Vuori I, et al. The injury mechanisms of osteoporotic upper extremity fractures among older adults: a controlled study of 287 consecutive patients and their 108 controls. Osteoporosis International 2000;11(10):822–31.
[27] Smeesters C, Hayes W, McMahon T. Disturbance type and gait speed affect fall direction and impact location. Journal of Biomechanics 2001;34(3):309–17.
[28] Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the timed up & go test. Physical Therapy 2000;80(9):896–903.
[29] Coppin AK, Shumway-Cook A, Saczynski JS, Patel KV, Ble A, Ferrucci L, et al. Association of executive function and performance of dual-task physical tests among older adults: analyses from the in Chianti study. Age and Ageing 2006;35(6):619–24.
[30] Melzer I, Marx R, Kurz I. Regular exercise in the elderly is effective to preserve the speed of voluntary stepping under single-task condition but not under dual-task condition. Gerontology 2009;55(1):49–57.