BIOMECHANICAL DIFFERENCES BETWEEN TAI-CHI PRACTICING AND ACTIVE ELDERLY DURING THE STAIR-TO-FLOOR TRANSITION

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Long-term Tai-Chi practitioners tend to have similar movement to healthy adults and exhibit movement strategies that reduce fall risk during stair-to-floor transition.We aimed to assess the differences during stair descent to ground in Tai-Chi elderly practitioners and active elderly. Fourteen regular Tai-Chi practitioners and fourteen active elderly participated. Whole-body kinematics and ground reaction forces (GRFs) were recorded synchronously by using motion analysis and a force platform. A t-test was used to test the differences between the groups. Both descent and forward walking step length and center of mass (COM) velocity, both horizontal braking and propulsive force and impulse, ankle range of motion (ROM) and total work in the sagittal plane, and maximum hip moment in the frontal plane had significant differences. Our results appear to support the benefits of long-term Tai-Chi training during the stair-to-floor transition.

KEYWORDS: stair negotiation, functional ability, balance

INTRODUCTION: With age-related declined in musculoskeletal, sensory, and central nervous systems, stair negotiation became one of the most challenging and hazardous tasks during daily activities for the elderly, where adaptive approaches may be necessary for reducing the risk of falling or slipping. In stair negotiation, the risk of falling from stair descent was three times more than stair ascent. Furthermore, a stair-to-floor transition occurs during the interaction with the stair and the changeover to level walking. Because of the transition between different levels and changes in movement patterns, the stair-to-floor transition had a higher risk of falling (Sheehan & Gottschall, 2011).

Regular exercise is a recommendation often used to resist the progressive decline in muscular abilities that are often associated with aging. Tai-Chi gait emphasizes lowering the center of gravity and larger steps, challenged the balance ability and the lower limb muscles, and the slow-motion characteristics of movement are quite suitable for older people. Tai-Chi has been promoted as a good choice of exercise for the elderly. It has been shown through long-term performance by healthy, community-dwelling older adults to improve both static and dynamic balance control with a reduction in unexpected falls (Li et al., 2005). During a stair-to-floor transition, it's believed that age-related weaknesses of the lower extremities can increase fall risk and incidence of injury. In measuring the limits of stability, Tai-Chi practitioners exhibited a better performance ability during single-leg jumping and landing (Gyllensten et al.,2010) and the perturbed single-leg stance (Tsang & Hui-Chan, 2005).

Furthermore, Tai-Chi training increased muscular capacity and activation that depicted greater knee co-contraction that effectively reduced fall risk during walking or stepping down (Tseng et al., 2007). Studies also report that these benefits of the Tai-Chi exercise improve with time (Sun et al., 2015). Therefore, long-term Tai-Chi practitioners may tend to exhibit movement behaviors that are more similar to younger adults, which have a faster velocity during a stair-to-floor transition where they perform greater forward propulsion (Prince et al. 1997).

The purpose of this study was to evaluate the differences in biomechanical parameters between the long-term Tai-Chi practitioners and the active elderly during the stair-to-floor transition.

METHODS: Fourteen regular Tai-Chi practitioners (10 males and 4 females; 73.6 ± 5.8 yrs; 1.62 ± 0.08 m; 58.3 ± 6.1 kg) (Tai-Chi group), and 14 active elderly (8 males and 6 females; 67.2 ± 1.7 yrs; 1.60 ± 0.08 m; 59.3 ± 10.7 kg) (control group) participated in this study. Exclusion criteria were any known neurological or orthopedic disease and any current difficulties impeding their typical locomotion. Ethical approval was obtained from the Review Board at the University. All participants provided their written informed consent before

participation in our study. There were no significant differences in body weight and height. Tai-Chi group practiced Yang 108 form style Tai-Chi for an average of 10 years with a range between 2 to 15 years, 4 to 5 days per week, for one hour per session. Control group of elderly performed leisure exercises (e.g., jogging, swimming) approximately over the same time per session.

A ten camera system (Vicon MX 13+, 250Hz) and one force plate (Kistler type 9287, 1000Hz) were synchronized to collect 3-D body motion and GRFs. Fifty-one reflective markers were used based on the Vicon plug-in gait marker placements. Additional markers were used on the greater trochanters, medial epicondyles of humerus, medial epicondyles of the femur, medial malleoli of tibias, and each of the 1st and 5th metatarsal heads. The force plate was inset into the ground, and the homemade stairs with no handrails were located 1 cm from the edge of the force plate. The staircase consisted of a series of three steps, each step with a rise of 18 cm and a run of 28 cm.

Participants were asked to perform the task barefoot to exclude any differences in reaction forces at the shoe/floor interface due to differences in footwear. They started the task at the top of the staircase, where a voice prompted them to begin to walk down the stairs with their right leg and at a self-selected speed in a step-over-step manner and ended after the participant walked forward on level ground for approximately 5 m. The speed and step length used were not restricted to simulate their typical performance. To prevent injury from an unexpected fall, two healthy young males served as spotters on each side. All participants completed at least five successful trials.

The Visual3D software (C-motion, Germantown, USA) was used to filter marker trajectories using a low-pass 12 Hz digital filter, develop all rigid body segments, and obtain COM. The GRFs were filtered within Visual3D using a second-order Butterworth bidirectional low-pass filter with a cut-off frequency of 45 Hz. A threshold of 50 N was used to determine the stance phase after stair descent. The GRF profiles were normalized by body weight. The stair-to-floor transition analysis began with toe-off of the right leg from the middle stair (36cm height) to toe-off of the right leg from the force plate. This movement was separated into two phases, the descent, and stance. These were defined as the period from toe-off from the central stair to the point of ground contact and from the point of ground contact to toe-off from the force plate, respectively. An independent t-test was used to test the biomechanical differences between groups. The significant level was set to 0.05.

RESULTS: The Tai-Chi group had both a longer descent step length and forward walking step length. The Tai-Chi group also performed with a similar descent velocity but with a higher forward walking stance velocity (Table 1). The vertical GRFs (Fig.1a) displayed two unequal peaks (*Fv1* and *Fv2*), where *Fv1* was higher than *Fv2* for both groups. There were no significant differences between the groups in *Fv1*, *Fv2*, and loading rate. For the anteroposterior GRFs (Fig. 1b), the Tai-Chi group showed a greater *Fh1* and *Fh2*. Also, Tai-Chi displayed greater braking and propulsive impulses (Table 2). During the stance phase, the Tai-Chi group had larger ankle ROM in the sagittal plane, and the Tai-Chi group generated greater total work from the ankle in the sagittal plane as well. In the frontal plane, the Tai-Chi group had a greater maximum joint moment in the hip (Table 3).

Table 1. Temporal, distance, and COM kinematic variables of the Tai-Chi and control group.

	Tai-Chi group	Control group
Descent time (s)	0.50 ± 0.05	0.48 ± 0.10
Forward walking stance time (s)	0.65 ± 0.03	0.63 ± 0.09
Descent step length (%BH)*	30.8 ± 3.5	22.8 ± 3.8
Forward walking step length (%BH)*	35.5 ± 2.1	31.6 ± 2.2
Descent step width (%BH)	4.95 ± 1.90	4.40 ± 2.49
Forward walking step width (%BH)	4.75 ± 1.84	4.41 ± 2.25
COM descent velocity (m/s)	0.70 ± 0.08	0.61 ± 0.09
COM forward walking velocity (m/s)*	0.94 ± 0.11	0.81 ± 0.16

* $p<.05$

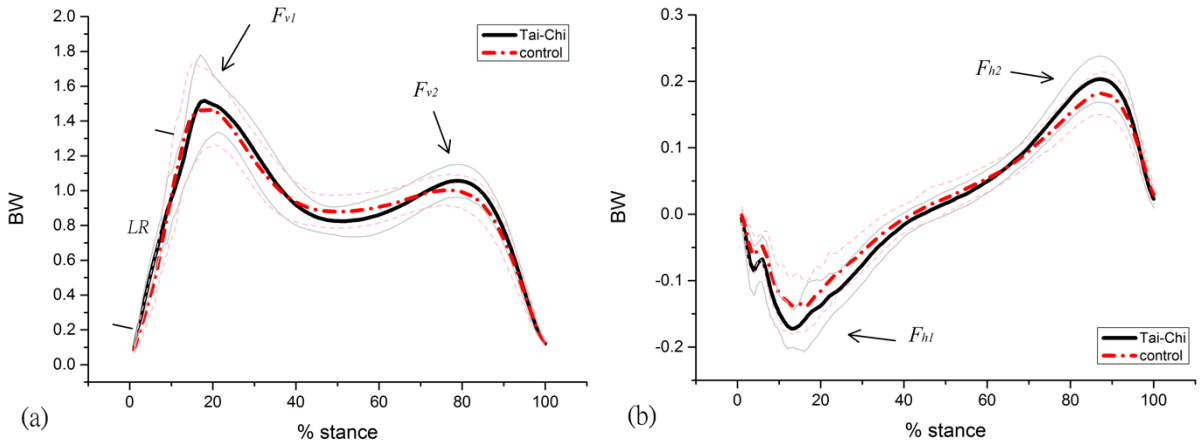

Fig.1: Normalized GRF profiles are depicted during the stance of the stair-to-floor transition. (a. vertical force, b. horizontal force.)

Table 2: GRFs, impulse, and loading rate between the Tai-Chi and control group.

	Tai-Chi group	Control group
Fv1 (BW)	1.68 ± 0.24	1.66 ± 0.17
Fv2 (BW)	1.08 ± 0.08	1.034 ± 0.062
Fh1 (BW)*	-0.20 ± 0.02	-0.154 ± 0.035
Fh2 (BW)*	0.21 ± 0.03	0.182 ± 0.033
Braking Impulse (BW*s)*	-0.036 ± 0.003	-0.018 ± 0.008
Propulsive impulse (BW*s) *	0.038 ± 0.006	0.027 ± 0.006
Loading Rate (BW/s)	14.97 ± 3.92	15.20 ± 3.93

* p<.05

Table 3: Kinematic and Kinetics variables during the stance phase.

		Tai-Chi group	control group
ROM in the sagittal plane (degree)	Hip	4.1 ± 1.2	4.4 ± 2.1
	Knee	15.1 ± 2.7	15.5 ± 4.5
	Ankle*	36.3 ± 2.6	31.2 ± 4.3
Maximum joint moment in the sagittal plane ($Nm*BH^{-1}*BW^{-1}$)	Hip	-0.55 ± 0.21	-0.45 ± 0.23
	Knee	-0.23 ± 0.06	-0.25 ± 0.10
	Ankle	-0.87 ± 0.11	-0.77 ± 0.22
Total work in sagittal plane (J)	Hip	0.90 ± 2.99	0.09 ± 2.29
	Knee	0.04 ± 4.80	0.72 ± 8.85
	Ankle*	-50.24 ± 9.52	-32.08 ± 18.54
Maximum joint moment in the frontal plane ($Nm*BH^{-1}*BW^{-1}$)	Hip*	-0.79 ± 0.11	-0.66 ± 0.10
	Knee	-0.30 ± 0.09	-0.25 ± 0.08

* p<.05. ROM, range of motion.

DISCUSSION: Positive effects of long-term Tai-Chi training resulted in differences in kinetics and kinematic variables during the stair-to-floor transition. Tai-Chi training had been shown to improve balance control, flexibility, and functional abilities in the lower extremities as well as during single limb activities (Gyllensten et al.,2010; Wu, 2012). In this study, a reduced step length resulted in decreases in horizontal GRFs and braking impulse in the control group. This may have indicated a conservative reduction in the mechanical load being placed on support limb (Hahn & Chou, 2004). Tai-Chi group showed a larger step length, as a tendency in younger adults (Bieryla & Buffinton, 2015), where they produced a higher braking GRF and braking impulse that may have been used to modulate their forward momentum. These findings may have indicated a more skilled use of the support limb while on the ground.
Older adults tend to negotiate stair descent at a slower speed compared to young adults (Mian et al. 2007). Long-term Tai-Chi training has been reported to resist the age-related decline in

lower extremity strength and walking speed while improving overall postural control (Sun et al., 2015). In our study, a greater peak propulsive force, propulsive impulse, step length on the ground, and COM forward walking stance velocity were shown in the Tai-Chi group similar to those reported in young adults (Prince et al. 1997). This may be attributed to better muscular abilities used to maintain movement speed rather than a strategy as in the control group where speed was reduced during the stair-to-floor transition (Tsang & Hui-Chan, 2005; Wu, 2012).
Prince et al. (1997) had mentioned that the elderly had a lower ankle dynamic ROM and a less vigorous push-off compared to young adults. However, we found the Tai-Chi elderly performed larger ankle ROM and generated more work from the ankle in the sagittal plane during the forward walking stance phase. A larger opposing internal hip abductor was essential to control hip adduction in stance (Mian et al. 2007). The Tai-Chi elderly had greater abductor moment than the healthy and active elderly; the Tai-Chi participants showed a better balance control around the hip joint; this could potentially contribute to a decreased risk of falling in old age.
The limitation of our study was that there had different gender within the group. Previous studies have indicated that gender in elderly influenced the kinetics during stair descent (Singhal et al., 2015). Our goal was to understand the overall influence of long-term Tai-Chi practice in the elderly, so we recruited a similar proportion of males and females in both groups to minimize these potential effects.

CONCLUSION: This study investigated the differences in GRFs, COM velocity, joint kinetics, and kinematics between Tai-Chi and typical elderly during a stair-to-floor transition. Our results appear to support some of the benefits of long-term Tai-Chi training during the stair-to-floor transition. Tai-Chi group demonstrated similar movement to the youth while with greater COM velocity and step length as well as greater propulsive kinetics during the stair-to-floor transition. These performance differences imply that long-term Tai-Chi practice may improve the functional ability and reduce the risks of falls in elderly that regularly use this exercise modality.

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