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THE TEMPOROSPATIAL CHARACTERISTICS OF TWO TYPICAL TAI CHI MOVEMENTS

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The purpose of this study was to examine and compare the three-dimensional centre of mass (COM) displacement and temporospatial features during performance of two typical Tai Chi movements, “Repulse Monkey (RM)” and “Wave-hand in Cloud (WHIC)”, with forward walking. A group of experienced male Tai Chi practitioners (n=15) between the ages of 65 to 75, participated in the study. It was found that stride width was larger for WHIC compared to walking while double-support time was longer for RM; both Tai Chi movements spent less time in single-support. RM and WHIC had larger mediolateral and vertical displacement of the COM compared to walking. The slow, gentle-shifting characteristics of two Tai Chi movements have unique biomechanical properties that may result in special training to postural control capacity.

KEY WORDS: Tai Chi, Temporospatial, Elders, Centre of Mass.

INTRODUCTION: Tai Chi is a traditional Chinese exercise that has been practiced for over 1200 years (Yang, 2010). Regular Tai Chi practice can help to maintain or improve balance, posture, breathing, muscle strength, digestion, cardiovascular and circulatory functions (Yang, 2010; Liu, & Frank, 2010; Li, Hong, & Chan, 2001; Man-Ch’ing & Smith, 1978). The American Geriatric Society and British Geriatric Society have recommended Tai Chi as an effective intervention to reduce the number of falls among the elderly (American Geriatric Society, 2011). Maintaining functional mobility is a major priority for the elders who wish to avoid hip fractures and fall-related injuries later in life (Daley & Spinks, 2000; Xu, Hong, & Li, 2008). Tai Chi is a safe exercise for the elderly because it is characterized by slow and graceful movements. Only a few studies have examined the kinematics and temporospatial characteristics of Tai Chi movements (Xu, Li, & Hong, 2003; Wu, Liu, Hitt, & Millon, 2004; Chau & Mao, 2006; Chan, Luk, Hong & 2003; Chen, Cheng, Liu, Chiu, & Cheng, 2010), but few studies have examined the kinematic features or dynamic displacement of centre of mass (COM) backward and sideway Tai Chi movements. Backward and sideways Tai Chi movements would have strong rehabilitation implication towards improving balance, strengthening hip muscles, and developing strategies to avert falls (Hackney & Earhart, 2009; Yang, Yen, Wang, Yen, & Lieu, 2005; Chua & Mao, 2006). The purpose of this study was to examine and compare the COM displacement and temporospatial characteristics of two Tai Chi movements, “Repulse Monkey” (RM) and “Wave-hand in Cloud” (WHIC) that contain Tai Chi backward and sideway stepping components, with forward walking.

METHOD: Fifteen male participants with more than 4 years experience in Yang- or Wu-styles Tai Chi participated in this study. Participants were from two local community centers in the Ottawa region. All participants were in good health according to initial screening using self-reported surveys. Table 1 shows the characteristics and makeup of the Tai Chi subjects.

Table 1. Participants’ Demographic Data, and Year(s) of Experience in Tai Chi Practice (n = 15)

	Mean ± SD
Age (yr)	65.5 ± 8.9
Body weight (kg)	70.0 ± 8.8
Height (cm)	166.7 ± 7.8
Body Mass Index (kg/m^2)	25.2 ± 2.6
Years of experience in practicing Tai Chi (yr)	14.3 ± 10.6

The participants were invited to the Human Movement Biomechanics Laboratory of the University of Ottawa where the study was conducted. They were asked to perform a minimum of five trials of the “Repulse Monkey” and “Wave-hand in Cloud” Tai Chi movements, along with five trials of forward walking. The participants all wore comfortable shorts, fitted t-shirt, and shoes. A total of 39-reflective markers was used to indicate the body’s anatomical landmarks in accordance with the Plug-in-Gait marker set (Oxford Metrics, Oxford, UK), as modified from the Helen-Hayes marker-set (Davis, Ounpuu, & Tyburski, 1991). The participants’ movement were recorded at 100Hz by the VICON Motion Analysis System (Vicon MX-13, Oxford Metrics, Oxford, UK) using ten VICON MX-13 cameras (Oxford Metrics, Oxford, UK). Four metal force plates (models 9286AA, Kistler Instruments Corp, Winterthur, Swtz; FP 4060-08, Bertec Corporation, Columbus, OH, USA) were used to define the instances of heel-strike and toe-off. These force plates were imbedded into an 8 m long walkway.

Two consecutive gait cycles for the left and right leg were analyzed for the temporospatial parameters, and the data was normalized to one gait cycle for further analysis. All data was derived from VICON Nexus (Oxford Metrics, Oxford, UK) and the Plug-in-Gait model (Oxford Metrics, Oxford, UK). As suggested by Xu, Li, & Hong (2003), the minimal position of the COM marker was subtracted from its maximal position in order to determine the total range of the COM displacement. Single- and double-support time, step length, and stride length was obtained from VICON Polygon 4.0 (VICON Motion Systems, Los Angeles, USA). Stride width, or the base of support, was determined by the side to side stepping distance between the feet from the left and right ankle markers on the lateral malleolus (Fukuchi & Duarte, 2008). Single- and double-support times were compared for the three movements by normalizing time to one full gait cycle. Single- and double-support times were reported as a percent of the total time for one stride. All five trials of the three movements were averaged for each participant. One-way ANOVA (Repulse Monkey × walking; Wave-hand in Cloud × walking) was used to compare average 3-dimensional COM displacement. Independent t-test was performed for the following single dependent variables: step length, stride width, single- and double-support times. Tukey’s post-hoc analysis was used if any main effects or significant interaction were found. Significance level was set at 0.05.

RESULTS: “Repulse Monkey” and “Wave-hand-in-Cloud” was performed symmetrically and continuously for both the right and left sides. Given the symmetry of the movements, only the results for the left limb (trailing limb) has been reported. The data for the temporospatial parameters and COM displacement are reported in Tables 2 and 3, respectively.

Table 2. Mean and standard deviation for temporospatial parameters for the left limb during the two Tai Chi and walking conditions (n=15). Single-support (SS) and double-support (DS) times were normalized by total stride time.

Parameter	Movement						
	Walking	Repulse Monkey	p-value	% diff	Wave-hand	p-value	% diff
Step Length (m)	0.72 ± 0.04	0.62 ± 0.03***	0.000	14	0.69 ± 0.06**	0.048	4
Stride Width (m)	0.65 ± 0.03	0.54 ± 0.04*	0.000	17	0.67 ± 0.04***	0.000	3
Stride Time (s)	1.34 ± 0.15	9.40 ± 2.77***	0.000	601	5.77 ± 3.01***	0.000	331
Norm. SS Time (%)	38 ± 2	14 ± 5***	0.000	63	12 ± 6***	0.000	68
Norm DS Time (%)	23 ± 3	69 ± 11***	0.000	200	21 ± 13***	0.000	9

** $p < 0.05$ vs. Walking ******* $p < 0.001$ vs. Walking

The data indicated that “Repulse Monkey” (RM) was performed at a much slower pace than walking with smaller backward steps. Step length and stride time were 1.12m and 9.40s for RM. Stride width was significantly smaller for RM than normal walking (0.54m vs. 0.65m, p = 0.000). On the other hand, “Wave-hand in Clouds” (WHIC) was a slow side-stepping movement that involved significantly wider lateral steps in close session. Stride width was 0.67m vs. 0.65m for WHIC and walking. Both RM and WHIC had significantly shorter normalized single-support times (14% and 12%, respectively) than walking (38%). The data shows that 61% of one gait cycle is spent in stance phase during the walking trial. For RM and WHIC, stance phase accounts for 83% and 33% of one gait cycle, respectively.

Table 3. Mean and standard deviation for total COM displacement range and maximal COM displacement during the two Tai Chi and walking conditions (n=15)

Direction	Movement				
	Walking	Wave-hand	p-value	Repulse Monkey	p-value
Mediolateral (m)	0.09 ± 0.03	1.02 ± 0.09***	0.000	0.30 ± 0.07***	0.000
Anteroposterior (m)	2.58 ± 0.13	0.10 ± 0.03***	0.000	1.35 ± 0.54***	0.000
Vertical (m)	0.05 ± 0.00	0.06 ± 0.01	0.073	0.07 ± 0.03**	0.019
Max-Mediolateral (m)	0.12 ± 0.04	0.55 ± 0.06***	0.000	0.17 ± 0.05	0.544
Max-Anteroposterior (m)	1.45 ± 0.09	0.18 ± 0.06***	0.000	0.40 ± 0.16***	0.000
Max-Vertical (m)	0.96 ± 0.06	0.95 ± 0.06	0.211	0.97 ± 0.07	0.445

** $p < 0.05$ vs. Walking

*** $p < 0.001$ vs. Walking

The data in table 2 shows that compared to walking, mediolateral (ML) displacement range of the COM was larger when performing RM. Displacement of the COM in anteroposterior (AP) direction during RM was 1.35 m compared 2.58 m for walking. On the other hand, WHIC involves notably larger ML displacement of the COM than walking; the ML position of the COM for WHIC and walking were 1.02 m compared to 0.09 m, respectively. The maximal ML COM displacement for WHIC was 0.55 m, compared to 0.12 m for walking. AP displacement of the COM was small during WHIC (0.10 m) since the movement was sideways. Vertical displacement of the COM was larger for both RM (0.07m) and WHIC (0.06m) compared with normal walking (0.05m). Moreover, RM had a significantly larger vertical displacement of the COM than normal walking.

DISCUSSION: *Temporospatial Parameters.* Data from our study showed that step length proportionally decrease as the task becomes more challenging. The values mentioned in our study are consistent with the values found in the study by Mao, Hong, & Li (2004). Stepping backwards during RM can be a challenging task; stride width was smaller for RM than WHIC and walking. Slower speeds during level-walking are believed to increase the risk of falling by increasing the time spent in single-support (Bassey, Fiatrone, O’Neill, Kelly, Evans, & Lipsitz, 1992; Fukagawa, Wolfson, Judge, Whipple, & King, 1995; Lajoie, Teasdale, Bard, & Fleury, 1993). However, in our current study, the unique feature of RM and WHIC was the shorter duration spent in single-support compared to walking. Double-support time was significantly longer for RM and WHIC when compared to walking. RM and WHIC are safe Tai Chi movements for the elders because the movement is slow and base of support is increased (Chua & Mao, 2006),. The results from our study suggest that RM and WHIC would be safe exercise for the elders to improve proprioceptive feedback because the time spent in single-support is reduced compared to walking.

The movement of Centre of Mass (COM). This is the first study to examine the COM displacement during backward and sideway Tai Chi movements. The displacement of the COM showed large directional and positional changes during Tai Chi performance, which suggests regular practice would help to train balance and postural stability (Xu, Li, & Hong, 2003; Mao, Hong, Li, Xu, & Wang, 2002). During forward "Brush Knee Twist Step", the AP, ML, and vertical COM displacements were 0.54, 0.18, and 1.22 m, respectively (Xu et al., 2003). These published data are comparable with the values obtained in our study, except the vertical COM displacement along the Z-axis was larger for "Brush Knee Twist Step". RM and WHIC elicit large changes to the backward and sideways displacement of the COM, respectively. For WHIC, the lateral displacement of the COM is large but over an equally large base of support between the two feet. Side-stepping is a preferable technique over cross-over in the event of a fall (Maki, 1997). Side-stepping exercises such as WHIC would help to reduce the risk of falls.

CONCLUSION: The findings outlined in this study demonstrate that the two Tai Chi movements, Repulse Monkey and Wave-hand in Cloud, have unique biomechanical characteristics compared to walking. The elders would benefit from performing these typical Tai Chi movements because they elicit gentle and fluid changes to position of the upper body mass. First, RM and WHIC are safe alternative movements because less time is spent in single-limb support and more in double-limb support. RM is slow backward-stepping movement characterized by large changes to the body's centre of mass. Both RM and WHIC had large mediolateral displacement of the centre of mass which could be used to improve balance and joint proprioception. Overall, practicing these Tai Chi movements is a safe way for the elders to potentially improve balance and reduce the risk of falls.

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