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THE CENTER OF MASS TRAJECTORY DURING FIXED-STANCE PUSH HANDS MOVEMENTS OF TAI CHI CHUAN

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The purpose of this study was to investigate how Tai Chi Chuan (TCC) skills affect the whole body center of mass (COM) during Tai Chi Chuan fixed-stance push hands movement. Four TCC experts with push hands movement experience for 10.3±1.7 years and four TCC beginners with 2.5±1.3-year experience were recruited in this study. Three-dimensional kinematics data of the TCC fixed-stance push hands movements were collected and COM displacement and velocity during the movements were analyzed. The patterns of the COM between two groups during the push hands movement cycle were similar, but the COM displacement and velocity were different. Our investigation reveals that the experience-related differences in whole body COM transfers are reflected in the push hands movement cycle.

KEY WORDS: Tai Chi Chuan, center of mass, push hands, velocity.

INTRODUCTION: The full double-limb support is one of the seven support patterns in performing a set of TCC movements (Hong & Li, 2007). A balance drill for the body's muscles and joints is offered by executing a number of complex maneuvers, such as the slow, relaxed manner of TCC push hands movement (Wang, et al., 2010). Performing push hands movement requires the TCC practitioners to get into semi-squatting, double-stance and weight-bearing maneuver which put a lot of pressure on the muscles of the lower extremities (Lai, et al., 1995). To keep balance in an upright standing position is assured when the center of mass (COM) is inside the base of support (Kuo, 1995; Pai, 2003). Besides horizontal COM positions, Pai & Patton (1997) emphasized the importance of the horizontal velocity of the COM in the prediction of the possible region for successful movement termination in the horizontal COM velocity-position phase plane. In standing, it requires ankle/hip movement maneuvers to keep the COM motion state stable without balance loss, and balance control can be achieved through the employment of these maneuvers. However, grasping and stepping maneuvers can be used to alter the base of support to achieve balance recovery more sufficiently when the disturbance is large (Pai, 2003).

A biomechanical investigation of TCC maneuvers application against a human opponent and the push hands movement characteristics is still insufficient. A complete understanding of the TCC practitioners' perception and their adaptation to their opponent's offense without losing their root can be achieved through the quantification of the forces transmitted in the lower extremity during a fixed-stance push hands movement between to human opponents. Therefore, the purpose of this study was to investigate how different TCC skills affect the COM trajectory during TCC fixed-stance double-handed push hands movements.

METHODS: Four TCC experts with push hands movement experience for 10.3±1.7 years and four TCC beginners with push hands movement experience for 2.5±1.3 years were recruited in this study. All the participants in the study reported no history of low back pain or any other musculoskeletal problems within the last three years. The study protocol was approved by the National Cheng Kung University Hospital Human Experiment and Ethics Department (ER-95-105), and all the participants signed committee-approved informed consents form. The Eagle® motion system with eight cameras (Motion Analysis Corp., Santa

Rosa, CA, USA) was used in this study for the collection of fixed-stance push hands movements at a sampling rate of 100 Hz. Each reflective marker was captured by at least two cameras. Marker data were smoothed using Woltring's generalized cross-validation natural spline filter. Four force plates (Kistler 9281B & 9286AA, Kistler Instrument Corporation, Winterhur, Switzerland) were used to measure the ground reaction forces at a sampling frequency of 1000Hz while the subjects performed the double-handed push hands movements with a fixed stance. All the measurements were performed synchronously. Thirty-four reflective markers were attached on the subject to define the coordinate system of the head, trunk, pelvis, upper arm, forearm, hand, thigh, shank and foot. A set of Tai Chi Chuan fixed-stance double-handed push hands movements constitutes four stages, each of which the two participants are involved in A) ward off vs. push, B) roll back vs. press, C) push vs. ward off and D) press vs. roll back (Fig. 1). In the following participants were instructed to perform the push hands movements without moving their own feet to make the opponent lose his balance. This test required an average of five successful trials in each push hands movement for data analysis. The positions of the segmental center of mass were determined using the anthropometric data of Dempster (1955). The relative mass and moment of inertia about the three principal axes of each segment are determined using the anthropometric data of McConville (1980). The push hands movement cycle can be classified into the neutralizing (ward off and roll back) and enticing circles (push and press). The results analysis of the neutralizing circle starts from the ward off movement (the initial position to maximum front knee flexion) to the roll back (with maximum rear knee flexion) and the results analysis enticing circle starts from the push movement (the initial position to the maximum front knee flexion) to the press (from push to maximum front knee flexion position). Mean and standard deviation of each kinematic variable of both legs was calculated, and then GRFs were compared using a Wilcoxon test which was used to test significant differences between the expert group and beginner group during TCC fixed-step double-handed push hands movements. Statistical significance was set at level of 0.05. SPSS version 13.0 (SPSS Inc., Chicago, IL) was used for all statistical analysis.

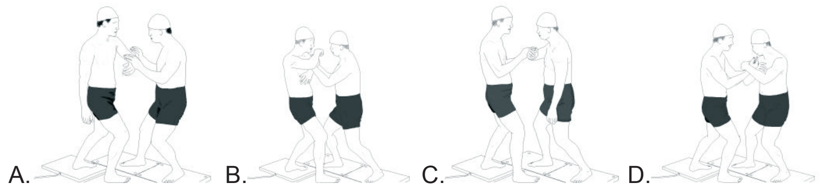

Figure 1: A set of TCC double-handed push hands movement (A: ward off vs. push B: roll back vs. press, C: push vs. ward off and D: press vs. roll back).

RESULTS: The patterns of the COM between two groups during the push hands movement cycle were similar, but the position and velocity were different (Fig. 2). The anterior-posterior component of COM displacement was 41.66±8.61 cm in the expert group and 33.71±6.42 cm in the beginner group and its vertical component was 5.21±1.60 cm and 3.30±1.09 cm, respectively (Table 1). The expert group shows a significantly greater vertical (p=0.001) displacement in the neutralizing circle than the beginner group. Moreover, it is also found that the expert group shows a significantly larger anterior-posterior (44.12±5.49 cm, p=0.006) and vertical (5.52±1.50 cm, p=0.0004) displacements in the enticing circle. The COM velocity was 0.29±0.08 m/s and 0.08±0.03 m/s in the anterior-posterior and vertical directions, respectively, in the expert group and 0.19±0.07 m/s and 0.04±0.02 m/s in the beginner group. Compared with the beginner group of TCC practitioners, the expert group had significantly greater COM velocity in the anterior-posterior (p=0.001) and vertical (p=0.001) directions in the enticing circle. The medial-lateral displacement of COM was not significantly different between two groups in both neutralizing and enticing circles.

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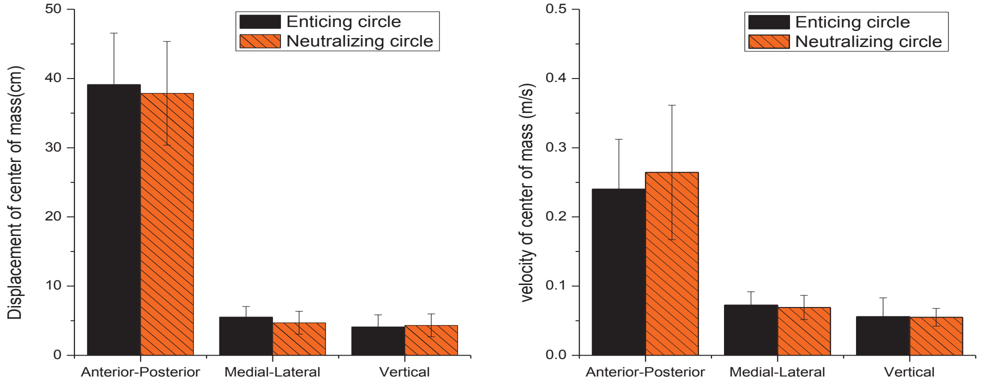

Figure 2: COM velocity-position of the neutralizing and enticing circles during TCC double-handed push hands movement cycle (left: displacement of COM; right: velocity of COM).

Table 1
Mean and standard deviation (SD) of COM velocity-position of the neutralizing and enticing circles during TCC double-handed push hands movement

Variables	Expert group		Beginner group		*p*
	Mean	SD	Mean	SD	
Neutralizing circle					
COM Displacment (*cm*)					
Anterior-posterior	41.66	8.61	33.71	6.42	.079
Medial-lateral	4.67	1.85	4.52	1.90	.959
Vertical	5.21	1.60	3.30	1.09	.001*
COM Velocity (*m/s*)					
Anterior-posterior	.29	.12	.23	.08	.134
Medial-lateral	.06	.02	.07	.02	.469
Vertical	.07	.01	.04	.01	.001*
Enticing circle					
COM Displacement (*cm*)					
Anterior-posterior	44.12	5.49	33.96	6.75	.006*
Medial-lateral	5.37	1.95	5.70	1.52	.535
Vertical	5.52	1.50	2.60	.78	.000*
COM Velocity (*m/s*)					
Anterior-posterior	.29	.08	.19	.07	.001*
Medial-lateral	.07	.02	.08	.04	.756
Vertical	.08	.03	.04	.02	.001*

$^*p < .05$

DISCUSSION: Our present findings illustrated the displacement and velocity of COM for TCC experts and beginners during double-handed push hands movement cycle. In this study, significant differences in the anterior-posterior and vertical displacement of COM between different TCC levels during neutralizing and enticing circles were observed. Moreover, differences in COM velocity between different TCC levels were found in the anterior-posterior and vertical directions in the enticing circle. The TCC experts showed large vertical displacement in neutralizing circle. In response to multi-directional perturbations, the COM has to be under the control of central nervous system. The physical aspects of push hands movement theory of TCC indicated the COM trajectory is smooth and steady (Olson, 1998), and fluctuation of COM trajectory generates acceleration which may influence one or two legs and cause balance loss during circle transfer. The COM displacement in AP direction was larger than ML and vertical directions, and its trajectory was large and smooth in expert group. The COM trajectory of beginner group is less smooth with smaller displacement (Fig. 2), thus, potential balance loss is anticipated. The present study predicts that if the anterior-posterior COM velocity-position trajectory is located inside the feasible region after enticing circle, the neutralizing response can still be carried out. The increased AP COM in the expert group suggests that they can have better control and direct their COM. Inclusion of the COM as a dependent variable is necessary to discern differences between TCC expert and beginner (Baird & Van Emmerik, 2009). Push hands movements are performed by two persons who have different practice experiences and whose TCC levels may not be equal. Therefore, the definition and selection of control group is not easy.

CONCLUSION: The skill differences described here indicate that TCC beginners may have certain difficulties with movement transfers, because of not only inability to generate the forces required but also disruptions in the temporal sequencing of the forces. Our investigation reveals that the experience-related differences with regards to COM transfers are reflected in the push hands movement cycle. Further investigation is required in order to determine whether it is possible to improve the circle of COM transfer in TCC beginners by practicing and training.

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