BIOMECHANICAL ANALYSIS OF THE DEFENSE TECHNIQUE IN TAI CHI PUSH HANDS

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Developed from traditional Chinese martial arts, Tai Chi (TC) exercise includes different forms and Push Hands which are more advanced movements. No biomechanical analyses of interactive Push Hands have been found. To analyze the kinematic, kinetic and electromyographic characteristics of Tai Chi Push Hands, an experienced master was asked to defend pushing by another person for three trials. The movements were videotaped and digitized using a motion analysis system combining electromyography and force plate data. The results indicated that a certain postural adjustment was adopted by the master. A clear shift of body weight from the front to the rear foot and larger mediolateral displacement of the center of gravity (COG) was observed. Low activities were in the upper body muscle groups, while higher electromyographic values were in the right rectus femoris and substantially higher activity in the left rectus femoris during the defense. It is concluded that the TC defensive technique includes postural adjustment which slightly changes the pushing force direction, and allows the rear leg to resist the incoming force.

KEY WORDS: Taijiquan, coordination, postural adjustment, martial arts, EMG.

INTRODUCTION:

Although Tai Chi (TC) is developed from traditional Chinese martial arts, it has become a popular exercise worldwide, especially among older people. Various types of TC have been developed. For example, Chen, Yang, Wu, and Sun styles are seen more often. Each style possesses its special features but the principles of TC with slow and smoothed motions remain the same.

Forms and Push Hands are both essential in TC. The former are basic routines performed by a single person, while the latter are more advanced movements requiring opponents to practice with. Proficiency in Push Hands will lead to abilities to feel the incoming force (Ting Chin), to know the appropriate reaction (Tung Chin), and to deal with all kinds of attacks (Omnipotence).

It has been shown that falls in the elderly can be reduced after TC training due to enhanced proprioception. Proprioception is the afferent information involving conscious sensation, joint stability, and postural equilibrium (Lephart, Pincivero, Giraldo & Fu, 1997). Xu et al. (2004) indicated that people practicing TC had better proprioception than other sport groups.

The center of gravity (COG) has been shown to remain low with well coordinated joint motions during TC push movements (Chan, Luk & Hong, 2003) in performing routines. TC gait has more double-support and movement direction is changed more often, when compared to normal gait. Moreover, larger plantar pressure were found at the the first metatarsal head and the great toe in TC exercise during single-support (Wu, Liu, Hitt & Millon, 2004). Despite that both forms and Push Hands are important exercises in TC, thus far only the effects of practicing forms have been analyzed. To our knowledge, no systematic investigation on TC Push Hands has been found. When facing a push or other kinds of attack, TC masters are capable of maintaining their balance (Cheng, 1985), but the scientific theory behind this technique remains unclear. Thus the purpose of the present study is to investigate the defensive techniques in TC Push Hands while resisting the incoming pushing force.

METHOD:

Data Collection: A TC master (age 69; height 1.60 m; weight 70 kg) participated in the study after given written informed consent. He has been practicing TC form (Cheng Tzu's style) and Push Hands for 40 and 30 years, respectively.

Two force plates obtained kinetic data on each foot of the master. The surface electrodes were placed on the right side of the upper body muscle groups including the triceps, deltoid, latissimus dorsi and erector spinae, and on both sides of lower body muscle groups including the rectus femoris, semitendinosus, and the medial head of gastrocnemius. Eight Eagle cameras (Motion Analysis Corporation) at 200 Hz, two Kistler Type 9281B force plates at 1000 Hz, and a MA-300 EMG System (Motion Lab Systems, Inc.) at 1000 Hz were synchronized during data acquisition. Anatomical landmarks were indicated by Helen Hays Marker Set (with 25 markers).
The master performed a maximal voluntary contraction (MVC) by isometric contraction against manual resistance of the muscles of interest before the actual experiment. In the formal experiment the master placed his left (backward) foot on the first force plate, and right foot on the second plate. The master laid his hands under the arms of the attacker, and was asked to defend pushing for three trials. It took about 5 sec for the master to move onto the force plates and get ready for the push after data recording started. The attacker then pushed with maximum force.

Data Analysis: The kinematic, kinetic, and EMG data were integrated by EVaRT Version 4.4.1 (Motion Analysis Corporation, Santa Rosa). A Butterworth filter with low-pass frequency of 6 Hz was used to smooth the kinematic data. Whole body COG position was calculated by previously reported segmental parameters (Winter, 1990). Changes in COG positions in the horizontal and vertical directions during movements were analyzed. EMG data were full-wave rectified, filtered by the Butterworth fourth order band-pass filter of 10-400 Hz, band-stop filter of 60 Hz, and then normalized by MVC values before getting the integrated EMG (IEMG) values.

RESULTS:
In resisting the push, the master initially lowered his COG position and remained at about the same height thereafter, and the COG generally moved forward and to the left (positive Y and negative X) (Fig. 1). Maximum COG displacement in the downward direction is about 30 mm, which is about half of that in the X direction, and less than 1/4 of that in the Y displacement.

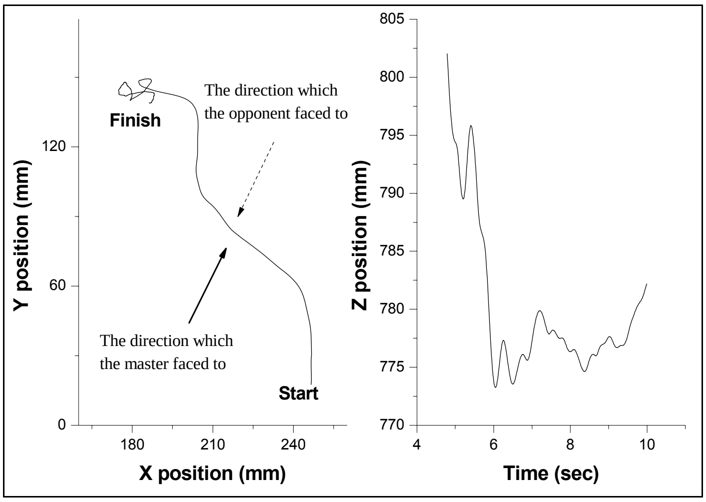

Figure 1: The path of the COG in the vertical (Z-axis) and horizontal (X- and Y-axis) directions.

Very minor changes in joint angles were observed since the master was able to resist the pushing force. Except for the ankle, lower limb joints generally extended during the master's defensive motion. Because the pushing force was acting on the trunk, the hip joint became more extended. The knee slightly extended and flexed during the 1st sec of resisting. Larger angular displacement was found in the left knee and ankle joints compared to the right side. Moreover, the left ankle angular displacements were larger than that of the knee (Fig. 2).

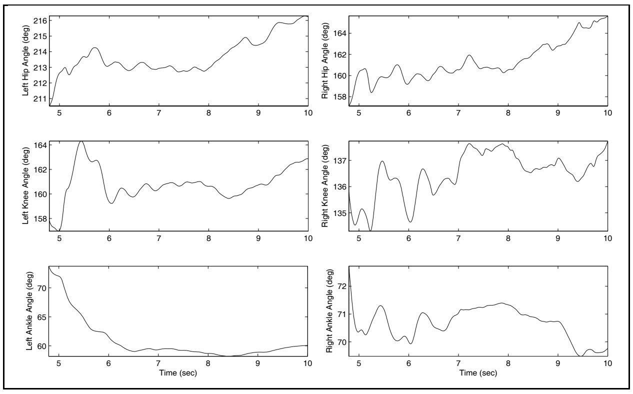

Figure 2: Variations in joint angles during the defense movement.

Two force plates indicated a distinct GRF pattern on each side (Fig. 3). When the master began to defend, his weight quickly transferred from the right to the left. During the defensive motion, the combined vertical force on both feet was 1.06 times the master's weight. The horizontal GRF on the left foot increased to about 0.3 BW while the force on the right foot is almost negligible.

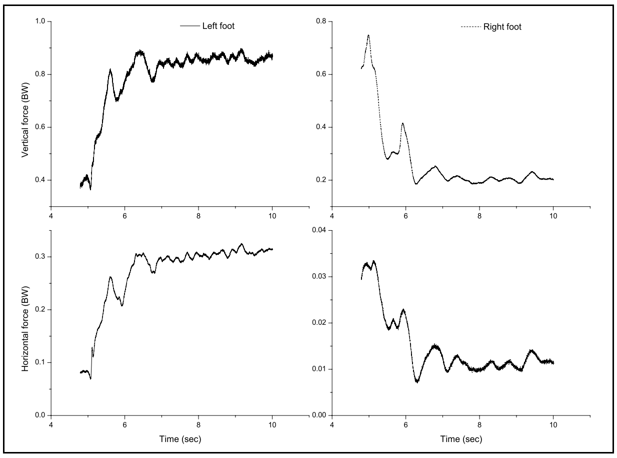

Figure 3: Vertical and horizontal GRF on the left and right foot.

IEMG values of different muscle groups are calculated (Table 1). The left (L) rectus femoris muscles showed the greatest activity. Higher EMG values are in the right (R) rectus femoris. The lowest EMG activities occurred in the left (L) semitendinous and the left (L) gastrocnemius.

Table 1 IEMG values of the ten muscles during the defensive movement.

IEMG values of the ten muscles			
L gastrocnemius	0.0791	R gastrocnemius	0.1522
L rectus femoris	1.2220	R rectus femoris	0.7145
L semitendinosus	0.0275	R semitendinosus	0.1343
R erector spinae	0.2922	R latissimus dorsi	0.2754
R deltoid	0.3539	R triceps	0.1810

DISCUSSION:

The purpose was to investigate the strategic reactions of an experienced TC master. The master could always resist the external pushing force without losing balance, while this skill cannot be executed by ordinary people.

The COG displacement (Fig. 1) during the master's defensive movement is mostly due to the focus on the rear (left) leg. COG moved to the left because of the use of the left foot to withstand the push immediately after movement onset. Although the trunk leaned backward, the joined effect of left knee extension and left ankle dorsiflexion resulted in a forward COG movement. The combination of joint angular displacement also caused slightly downward COG movement.

The GRF variation also shows clearly that the master used his rear (left) leg to withstand the push because only small GRF values are observed on the forefoot (Fig. 3). It is noteworthy that even though the pushing movement appears in the horizontal direction, the combined left-right vertical GRF exceeds the body weight (1.06 BW). This means that, while the pushing force was mostly horizontal (0.3 BW), about 1/5 of the force was directed downward. It seems that the master's subtle postural adjustment caused unaware downward component and consequently reduced horizontal component of the pushing force from the attacker. This technique of probably results from the combined abilities of "Listening to Strength" and "Interpreting Strength".

The high IEMG values the rectus femoris muscles on both sides are due to the squat posture adopted during the entire movement (Table 1). These values are higher at the beginning and lower at the end probably because of less pushing force exerted by the attacker due to fatigue. Although it appeared that the master resisted the push with his arms, his rear leg actually played the most important role. Thus, muscle activities in the R triceps and deltoid muscles were not as high as that in the L rectus femoris.

CONCLUSION:

The current study examined the kinematics, kinetics, and EMG characteristics of a fundamental defense technique of TC Push Hands. An experienced TC master's posture adjustment creates a downward component of the seemly horizontal pushing force and allows the rear leg to resist the incoming force, resulting in substantial activities in the rectus femoris muscles.

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Acknowledgement

The authors appreciate the financial support for this study by National Science Council, Taiwan (NSC 95-2413-H-006-015).