GROUND REACTION FORCE AND POSTURAL ADAPTATION OF THE PUSH MOVEMENT IN TAI CHI

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INTRODUCTION
The basic principles of Tai Chi Chuan (TCC) are the same in spite of several different schools or styles [1]. For increasing one's skill, Tai Chi is practiced from single action to a complete boxing frame and learned from a single-practitioner practice to push-hands, two-person training. The push-hands in TCC is an important skill to make the opponents lose their own balance while practitioners still maintain the stability through changing defensive positions without losing ground. How do Tai Chi (TC) practitioners sense and adapt themselves to their opponent’s demands without losing their root? The purpose of this study was to investigate postural stability in terms of ground reaction forces during pushing hands in Tai Chi.

METHODS
Four male community-dwelling adults (height: 167.3±5.8cm, weight: 75.5±9.9 kg) with push-hands practice for 7.6±6.2 years were recruited in this study. An eight-camera Expert Vision Eagle motion analysis system and two Kistler force plates were used to collect kinematic data and the ground reaction force at 1000 Hz sampling rate, respectively. 31 retro-reflective markers were placed on anatomical significant locations that determine embedded axes for segments. Subjects bowly standed with an opponent (height: 170cm, weight: 73 kg) standing facing them with his arms cross in front of the chest. In the beginning of the task, subjects were required to remain as stable as possible but relaxed, standing shod with front and rear feet on two platforms while the opponent leaned his body weight on them. In the following subjects were instructed to perform push movement without feet movement to make the opponent lose his balance. Each session includes five successful trials. Subjects were allowed to practice pushing opponent. The kinematic data of the lower extremities were analyzed during the whole movement. The resultant ground reaction forces (F) were decomposed into medial-lateral force (F_M-L), anterior-posterior force (F_A-P) and vertical force (F_V). In addition, the fraction of the force in pushing the opponent was defined as:

\[ \text{Fraction Opponent Force} = \frac{\text{ground reaction force – body weight of Tai Chi player}}{\text{body weight of the opponent}} \]

RESULTS AND DISCUSSION
The subjects took average 0.79 ± 0.38 seconds to complete the whole push movement. During the push movement, subjects kept in a bow standing position and the major range of motion happened in sagittal plane. The mean range of motion of the hip, knee and ankle joints is 37-43, 24-63 and 13-27 degrees in flexion, respectively for the front leg and 5-24, 37-63 and 32-36 degrees in flexion, respectively for the rear leg. In contrast to Chan’s study [2], three joints of the lower limbs flexed by the downward sloping pattern. The mean COP excursion to two-heel distance ratio is 72 %, less than that in push-hands, 87 %. Table 1 shows the ground reaction forces during push movement. The maximal anterior-posterior shear force was 24.4±56.7 N and 252.14±104.7 N toward anterior and posterior direction, respectively. Maximum mediolateral shear in right side was 25.56±13.78 N and 57.34±43.99 N in left side. The maximal ground reaction force was up to 1.37±0.24 times of body weight of Tai Chi player. The findings indicated that the TC player exerted 1.11±0.16 times of opponent’s body weight to make him lose balance while the TC player could maintain standing still. The major changes of ground reaction force during the push movement were the increase of vertical and posterior shear forces. The posterior shear and vertical forces play the same roles in making opponent lose balance. In general, while pushing a heavy object, we can direct the exerted force in a direction other than the horizontal to increase the horizontal component of the applied force [3]. At initial stage, posterior force from resistance of opponent in TC push movement was absorbed and transformed into anterior force. In spite of the differences in pushing strategies, TC participants were still able to adjust the magnitudes and directions of force exertions against the opponent. The changing posture and direction of the applied force may have important implications for the potential mechanisms and result in balance loses.

CONCLUSIONS
By examining ground reaction forces, how the Tai Chi player makes opponents lose their own balance while still maintaining the stability could be understood. As a result, F_A-P plays important roles in push movement and posterior force exerted from the opponent was absorbed and transformed into anterior force to help TC practitioners remain stable.

REFERENCES

ACKNOWLEDGEMENTS
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**Table 1:** Ground reaction forces during push movement.

<table>
<thead>
<tr>
<th>GRF</th>
<th>Anterior-posterior force (N)</th>
<th>Medial-lateral force (N)</th>
<th>Vertical force (N)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>F_{A-P}</td>
<td>F_{M-L}</td>
<td>F_V</td>
</tr>
<tr>
<td>Min</td>
<td>240.00</td>
<td>57.34</td>
<td>174.60</td>
</tr>
<tr>
<td>Max</td>
<td>252.14</td>
<td>104.70</td>
<td>252.14</td>
</tr>
<tr>
<td>Mean ±SD</td>
<td>-252.14 ± 104.70</td>
<td>-57.34 ± 43.99</td>
<td>174.60 ± 252.14</td>
</tr>
</tbody>
</table>

\[ ^*_{FF_{A-P}, FF_{M-L}, FF_{V}}: \text{Fraction opponent force in anterior-posterior, mediolateral, and vertical directions, respectively.} \]