

Research article

The Effects of Tai Chi Chuan Combined with Vibration Training on Balance Control and Lower Extremity Muscle Power

Pao-Hung Chung^{1,2}, Guan-Lun Lin³, Chiang Liu¹, Long-Ren Chuang⁴ and Tzyy-Yuang Shiang³✉

¹ Graduate Institute of Sports Equipment Technology, Taipei Physical Education College, Taipei, Taiwan; ² Department of Physical Education, and ³ Graduate Institute of Exercise and Sports Science, National Taiwan Normal University, Taipei, Taiwan; ⁴ Department of Chinese Martial Arts, Chinese Culture University, Taipei, Taiwan

Abstract

The aim of this study was to determine whether performing Tai Chi Chuan on a customized vibration platform could enhance balance control and lower extremity muscle power more efficiently than Tai Chi Chuan alone in an untrained young population. Forty-eight healthy young adults were randomly assigned to the following three groups: a Tai Chi Chuan combined with vibration training group (TCV), a Tai Chi Chuan group (TCC) or a control group. The TCV group underwent 30 minutes of a reformed Tai Chi Chuan program on a customized vibration platform (32 Hz, 1 mm) three times a week for eight weeks, whereas the TCC group was trained without vibration stimuli. A force platform was used to measure the moving area of a static single leg stance and the heights of two consecutive countermovement jumps. The activation of the knee extensor and flexor was also measured synchronously by surface electromyography in all tests. The results showed that the moving area in the TCV group was significantly decreased by 15.3%. The second jump height in the TCV group was significantly increased by 8.14%, and the activation of the knee extensor/flexor was significantly decreased in the first jump. In conclusion, Tai Chi Chuan combined with vibration training can more efficiently improve balance control, and the positive training effect on the lower extremity muscle power induced by vibration stimuli still remains significant because there is no cross-interaction between the two different types of training methods.

Key words: Composite vibration training, postural control, center of pressure, countermovement jump.

Introduction

Regular participation in Tai Chi Chuan can improve balance control (Tsang and Hui-Chan, 2004; Tsang et al., 2004; Wu, 2002). Because the body movements are slow, smooth and well-coordinated with a lowered center of gravity for the various forms throughout the exercise period (Hong et al., 2000), the benefits of Tai Chi Chuan that were found included enhancements of the knee extensor and flexor strength (Li et al., 2009; Wu et al., 2002), proprioception (Xu et al., 2004) and the reflex reaction time of the lower extremities (Fong and Ng, 2006). However, Tai Chi Chuan has its shortcomings in improving performance; a previous study showed that the achievement of a significant effect required prolonged and sustained participation (Xu et al., 2005), such as for sixteen weeks or more (Li et al., 2009). Moreover, for the Tai Chi Chuan participants to make a significant improvement in balance control over four weeks, intense training was

required for 90 minutes six times a week (Tsang and Hui-Chan, 2004). Although interest in Tai Chi Chuan as a form of physical exercise has been steadily increasing (Taylor et al., 2004), the bulk of the research participants and practical participants still belong to the elderly population. Not many young people participate in Tai Chi Chuan due to their busy lifestyle or their regard of Tai Chi Chuan as an inefficient training method.

In recent years, there were several review papers and meta-analyses indicating that through the intervention of whole-body vibration (WBV), muscle strength and power could be improved after acute or chronic excitation (Luo et al., 2005; Marin and Rhea, 2010a; Marin and Rhea, 2010b; Mikhael et al., 2010; Wilcock et al., 2009), which even occurred for untrained adults (Osawa and Oguma, 2011). Most of the training periods were usually set at between four to eight weeks (Cardinale and Bosco, 2003; Luo et al., 2005; Rehn et al., 2007). The effects of WBV training were from “tonic vibration reflex” (TVR), in which vibration stimuli on the primary spindle endings induce more muscle contractions due to more synchronous motor unit recruitments (Eklund and Hagbarth, 1966). Although WBV training also enhanced the performance of athletes (Cochrane and Stannard, 2005; Fagnani et al., 2006), it had no improvements on either static or dynamic balance control in young people after four months (Torvinen et al., 2002). Furthermore, not all WBV training was effective, and the effects differed when using different equipment and methods (Giminiani et al., 2009; Luo et al., 2008). Consequently, WBV training was also combined with other training methods, such as conventional weight training (Rønnestad, 2004), upper limb muscle training (Moran et al., 2007) or isometric training together with vibration stimuli (Mischi and Cardinale, 2009). The results showed that the combined WBV training was more effective than the isolated training methods (Delecluse et al., 2003).

It is worth determining whether combining different types of training methods can efficiently enhance specific performance or whether the training effects are reduced due to cross-interactions. However, the features of the Tai Chi Chuan movements seem suitable for vibration stimuli during execution. Because combining WBV training could increase the training effects, no previous studies have discussed the effects of Tai Chi Chuan combined with vibration stimuli, mainly because of the limitations of the vibration platform size. It is impossible to perform conventional Tai Chi Chuan on commercial vi-

bration platforms. Therefore, the aim of this study was to determine whether performing Tai Chi Chuan on a customized vibration platform could enhance balance control and lower extremity muscle power more efficiently than Tai Chi Chuan alone in an untrained young population. The hypothesis was that vibration stimuli would recruit more motor units of the lower extremities during the Tai Chi Chuan movements, thus inducing more and stronger muscle contractions. This process was more efficient than Tai Chi Chuan alone in terms of balance control while also simultaneously enhancing the muscle power of the lower extremities.

Methods

Study design

This study had a randomized, controlled experimental design. A three-group pre-post design was used in this study to examine the effects of eight weeks of Tai Chi Chuan with a customized vibration platform on balance control and lower extremity muscle power. The three groups included a Tai Chi Chuan combined with vibration training group, a Tai Chi Chuan group and a control group. Balance control was measured in the pre- and post-test conditions by the moving area of a static single leg stance with eyes closed. The lower extremity muscle power was measured by the heights of two consecutive countermovement jumps. The activation of the knee extensor and flexor during the static single leg stance and two consecutive countermovement jumps was also measured synchronously by surface electromyography.

Participants

Forty-eight healthy young adults (25 males and 23 fe-

males; age, 20.6 ± 1.4 yrs; height, 1.67 ± 0.09 m; body mass, 61.8 ± 9.4 kg) were recruited in this study. The inclusion criteria were being between 18-22 years old and having no Tai Chi Chuan training experience. The exclusion criteria included having any visual impairment, vestibular injury, proprioceptive or cerebellar lesion or any other major disease, injury or fracture within the previous three months. The CONSORT (consolidated standards of reporting trials) flowchart of the study is shown in Figure 1. The participants were required to be informed and to provide written consent before enrollment into this study. This study has been approved by the Institutional Review Board of Taipei Medical University.

All participants were randomly assigned to a Tai Chi Chuan combined with vibration training group (TCV; 9 males, 7 females), a Tai Chi Chuan group (TCC; 8 males, 8 females) or a control group (CON; 8 males, 8 females). The TCV and TCC groups started training within one week after a pretest; the CON group maintained their normal daily activities during the entire period. One male participant from the TCC group was excluded due to incomplete training participation. Because both genders were equally assigned to each group, there was no gender difference for intervention and no significant differences were found in the anthropometric characteristics among the three groups ($p > 0.05$), as shown in Table 1.

Table 1. Means (\pm SD) of physical characteristics in the TCV, TCC, and CON groups.

	TCV (N = 16)	TCC (N = 15)	CON (N = 16)
Age (yrs)	20.6 (1.0)	20.0 (1.6)	21.1 (1.5)
Height (m)	1.68 (.07)	1.66 (.12)	1.68 (.09)
Body mass (kg)	62.5 (10.4)	63.0 (10.3)	59.9 (7.5)

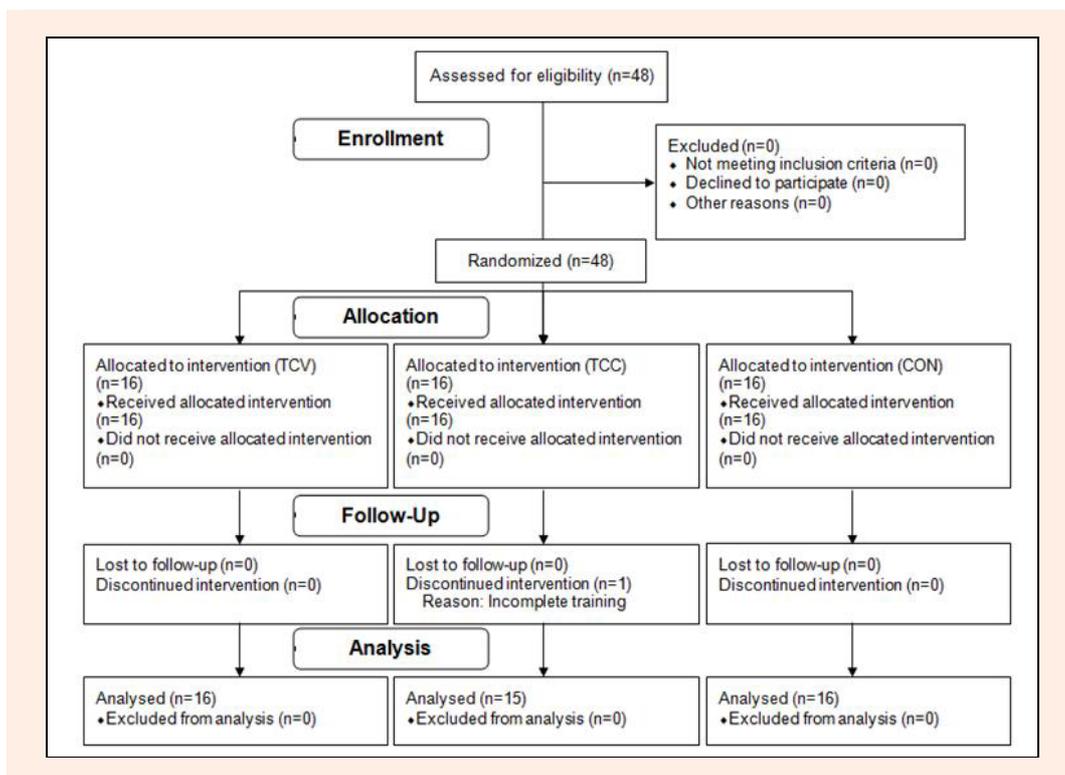


Figure 1. CONSORT flowchart of this study.

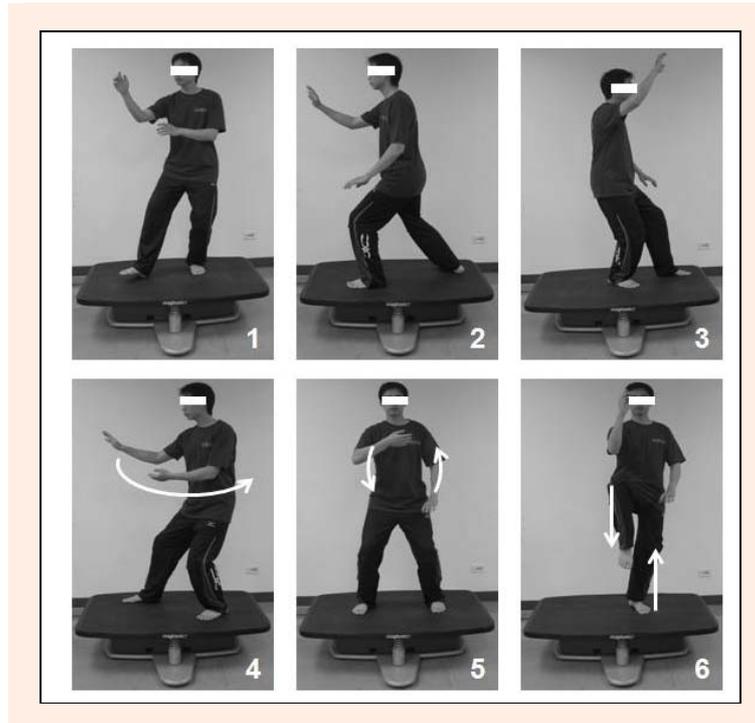


Figure 2. Performing reformed Tai Chi Chuan routine on a customized vibration platform. **Top:** basic standing (1-Lifting hands, 2-Brush knee and twist step, 3-White crane spreads its wings); **Bottom:** single move (4-Grasp sparrow's tail, 5-Waving hands in clouds, 6-Golden pheasant stands on one leg).

Training procedures

The customized vibration platform (90 cm long and 120 cm wide) was designed for the performance of static and dynamic Tai Chi Chuan movements. According to the finding on the highest reflex response in the thigh muscle during WBV (Cardinale and Lim, 2003a) and the mean frequency of a vertical vibration platform for chronic strength training (Marin and Rhea, 2010a), the frequency was set to 32 Hz and verified by the number of oscillations per second in the center of the platform. To reduce interference in performing Tai Chi Chuan movements, the peak-to-peak displacement was set to 1 mm and verified at the same location. Therefore, the maximum acceleration of the vibration platform was calculated as 4 g (Lorenzen et al., 2009). To match the range of Tai Chi Chuan movements on the platform, a reformed Tai Chi Chuan routine was created by Tai Chi Chuan experts (Figure 2). The main difference between the conventional and reformed Tai Chi Chuan was to change the direction of movement from straight forward to turning around.

The TCC and TCV groups practiced either Tai Chi Chuan alone or in combination with vibration stimuli three times a week for eight weeks, for approximately 30 minutes each time. Both of the groups were asked to wear cotton-soled Kung Fu shoes during the Tai Chi Chuan movements. The Tai Chi Chuan program gradually progressed from simple to complex exercises. The first, second and eighth weeks included “simple standing”. The third and fourth weeks included a “single move”. The fifth, sixth and seventh weeks included a “routine move”. After five minutes of warm-up, the TCV group performed Tai Chi Chuan on the vibration platform for one minute in three sets, for two minutes in three sets and for three min-

utes in two sets. There was a one-minute break between each set and a four-minute cool down. The TCC group performed the same program of Tai Chi Chuan as the TCV group but on flat ground. The CON group did not participate in any type of strength training and maintained their normal daily activities, and they were asked to abstain from any lower extremity training or jump practice.

Test procedures

After a standardized warm-up and stretching, the participants were tested before and after eight weeks of training, and the post-test was performed the week after the last intervention. The test procedures were completed in the following order: (1) the static single leg stance test with eyes closed, in which the participants had to stand on their dominant leg with both hands on waist for ten seconds and to control their body sway as much as possible; (2) the consecutive countermovement jump test, in which the participant had to perform two consecutive countermovement jumps as high as possible without shoes and with both hands on waist, remaining perpendicular to the ground, where the first jump included a squat prior to taking off and a progression through the stretch shortening cycle (SSC) after landing, which was followed immediately by the second jump; and (3) the maximal voluntary contraction (MVC) test, in which the participant had to perform the isometric knee flexion and extension at leg flexion angle of 120° on the dynamometer (Biodex system 3 pro, Shirley, NY) with restraining straps over the pelvis, trunk, and contralateral thigh, where the resultant MVC value was used to normalize the muscle activation. A successful trial of consecutive countermovement jump test was regarded that the participant could finish the

whole jump movement smoothly with full extension of the leg and all tests required three successful trials. Rest intervals were allowed for three minutes between trials and for over one hour between tests to prevent neuromuscular fatigue.

The static single leg stance test and the consecutive countermovement jump test were performed on a force platform (BP600900; Advance Mechanical Technology Inc., USA), and active electrodes with an integral 500-Hz low-pass filter (TSD 150A; BIOPAC System Inc., USA) were used to record the surface electromyography (EMG) of the knee extensor and flexor of the m. rectus femoris and the long head of the m. biceps femoris of the dominant leg. The electrodes were attached to the anatomic reference points according to the SENIAM (surface electromyography for the non-invasive assessment of muscles) recommendations (Hermens et al., 2000), and the single ground electrode was fixed on the ipsilateral knee. Data acquisition system (MP150; BIOPAC System Inc., USA) with AcqKnowledge 3.9.1 software was used to synchronously collect data from both the force platform and the active electrodes, with a sampling rate of 1000 Hz. LabView 8.5 (National Instruments, USA) software was used for signal processing and analysis. The EMG filter frequency was set to 10-500 Hz, and the MVCs before and after training were used for normalization, providing measurements in terms of % MVC. The root mean square (RMS) was used to represent the muscle activation.

Balance control was represented by the largest moving area (cm²) of the center of pressure (COP) of a static single leg stance with eyes closed (Mak and Ng, 2003). This value was calculated from the force and moment collected by the force platform, and the x-axis and y-axis positions were obtained according to the following formulas: $COP(x, y) = My/Fz$ and Mx/Fz . To avoid extreme values, 95% of half of the maximum x-axis and y-axis displacements within 10 seconds were defined as the long radius and short radius of the ellipse, respectively. The moving area that was calculated from the ellipse formula represented the ability for balance control. The activation of the knee extensor and flexor was assessed by the RMS of the surface EMG over 10 seconds.

The lower extremity muscle power was represented by the height (cm) of two consecutive countermovement jumps (CMJ). This value was calculated from the vertical force collected by the force platform, using the time in the air (t) and the following formula: $height = gt^2/8$, where $g = 9.81 \text{ m}\cdot\text{s}^{-2}$. To assess the activation of the knee extensor and flexor, the velocity was obtained from the quadratic integral of the vertical force, and the zero velocity was used (Linthornes, 2001). The best two trials were selected, and their average was analyzed for all tests.

Statistical analysis

SPSS software v12.0 (SPSS Inc., Chicago, USA) was used for statistical analysis. The test-retest reliability of each dependent variable was assessed by intraclass correlation coefficients (ICC). For the balance control and lower extremity muscle power analyses, a two-way ANOVA for repeated measures (3 groups \times 2 times) as-

sessed the significance of changes between the pre- and post-tests. Tukey's method was used for post-hoc comparisons in cases where the ANOVA showed statistically significant differences, with the significance level set to $p < 0.05$. Partial eta squared (η^2) and observed power (OP) values were also calculated to complete the analysis.

Results

Test-retest reliability

Only the activation of the knee flexor in the first jump and the extensor in the second jump showed moderate test-retest reliability (0.584 and 0.690), and the ICC values of the other dependent variables were always greater than 0.700 (between 0.729 to 0.960). The results showed that all measures provided evidence of substantial reliability.

Balance control

The moving area was significantly different ($F = 8.142$; $\eta^2 = 0.270$; $OP = 0.947$) among the groups (Figure 3). In post-hoc comparisons, the TCV and TCC groups had significantly smaller moving areas than the CON group. In the within-group simple main effect comparisons, the TCV group showed a significant decrease of 15.3% ($F = 5.634$; $\eta^2 = 0.273$; $OP = 0.603$), and the CON group showed a significant increase of 24.4% ($F = 13.031$; $\eta^2 = 0.465$; $OP = 0.921$). No significant decrease was found before and after 8-weeks interventions in the TCC group ($F = 1.206$; $\eta^2 = 0.079$; $OP = 0.176$).

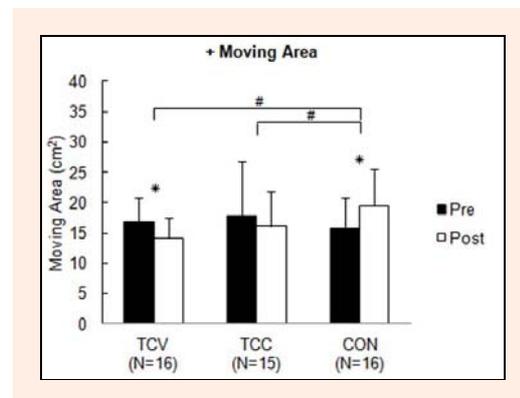


Figure 3. Mean and SD of moving area in the TCV, TCC, and CON groups. # indicated that the posttraining values in the TCV and TCC groups were significantly lower than the CON group after 8-weeks interventions. * indicated that significantly different between pre- and post- training values. + indicated that a significant interaction (group \times time) effect ($P < 0.05$).

The activation of the knee extensor was significantly different ($F = 3.322$; $\eta^2 = 0.131$; $OP = 0.599$) among groups, but the post-hoc comparison between and within groups revealed no significant difference (Table 2). The TCV group showed a decreased activation of the knee extensor by 27.7% after training.

Lower extremity muscle power

The first jump height showed no significant difference, but the second jump height was significantly different ($F = 3.483$; $\eta^2 = 0.137$; $OP = 0.621$) among groups (Figure 4). In the post-hoc comparisons, the TCV group had a

Table 2. Mean and SD of muscle activation (in %MVC) on balance control and twice consecutive countermovement jump before (pre) and after (post) 8-weeks interventions in the TCV, TCC, and CON groups.

	TCV (N = 16)		TCC (N = 15)		CON (N = 16)		P
	pre	post	pre	post	pre	post	
Balance control							
Knee extensor	8.4 (6.3)	6.1 (4.8)	5.3 (5.5)	5.2 (5.3)	5.5 (5.2)	6.5 (6.4)	.045 ⁺
Knee flexor	12.7 (6.1)	12.3 (8.0)	9.8 (9.5)	9.1 (6.5)	10.7 (8.0)	11.5 (7.1)	.772
First jump							
Knee flexor	22.2 (9.6)	14.2 (4.0) *	23.4 (8.7)	29.0 (18.0)	23.6 (15.0)	22.5 (10.8)	.028 ⁺
Knee extensor	115.9 (28.7)	104.1 (19.7) *	93.5 (33.8)	91.1 (31.4)	106.8 (31.8)	107.9 (32.9)	.159
Second jump							
Knee flexor	36.2 (20.3)	29.8 (16.4)	32.2 (16.8)	24.8 (19.1)	40.0 (20.5)	40.5 (21.4)	.405
Knee extensor	106.5 (30.9)	97.2 (26.1)	63.8 (36.8)	62.3 (30.5)	100.2 (31.1)	101.9 (24.3)	.652

+ refers to a significant interaction (group × time) effect. * indicated that posttraining values were significantly lower than pretraining values (p < 0.05).

significantly higher jump height than the CON group. In the within-group simple main effect comparisons, the TCV group showed a significant increase of 8.14% (F=21.832; $\eta^2=0.593$; OP=0.992).

The activation of the knee flexor in the first jump was significantly different among groups (F=3.900; $\eta^2=0.151$; OP=0.674) (Table 2). In the within-group simple main effect comparisons, the TCV group showed a significant decrease of 36.1% (F = 13.351; $\eta^2 = 0.471$; OP = 0.927). The activation of the knee extensor in the first jump showed no significant difference, but the TCV group showed a significant decrease of 10.2% (F = 8.455; $\eta^2 = 0.360$; OP = 0.776) in the within-group main effect comparisons. The activation of both the knee extensor and flexor in the second jump showed no significant differences.

Discussion

There have been more than one hundred studies published showing that isolated or composite WBV training induced effects on the lower extremities, but the effects varied because of different equipment, settings or training methods (Giminiani et al., 2009; Luo et al., 2008). Moreover, the size of most commercial vibration platforms limits the range of movement; therefore, the postures during WBV

training are usually a static standing or squatting. Although the task is easily achieved, this type of vibration training is not attractive for regular participation. Therefore, a previous study developed a larger vibration training equipment to combine vibration and resistance training (Kvorning et al., 2006). In this study, the development of a customized vibration platform (size: 90×120 cm) to match the range of Tai Chi Chuan movements was verified to be feasible after an eight-week training period.

After eight weeks of Tai Chi Chuan combined with vibration training, the balance control was significantly improved. The participants in both the TCV and TCC groups used less activation of the knee extensor and flexor after training to control their body sway. Although the TCC group still showed a decreased trend of moving area after 8-weeks interventions and many studies have confirmed that Tai Chi Chuan could improve balance control, a long duration or intensive training was required for a significant effect to be achieved (Tsang and Hui-Chan, 2004; Xu et al., 2005); moreover, a previous study also showed that the balance test did not change after eight weeks of WBV training in older adults (Marín et al., 2011), and three months of high-frequency WBV training were suggested to significantly improve balance control (Cheung et al., 2007). To maintain a stable posture, good coordination of the neuromuscular system is required.

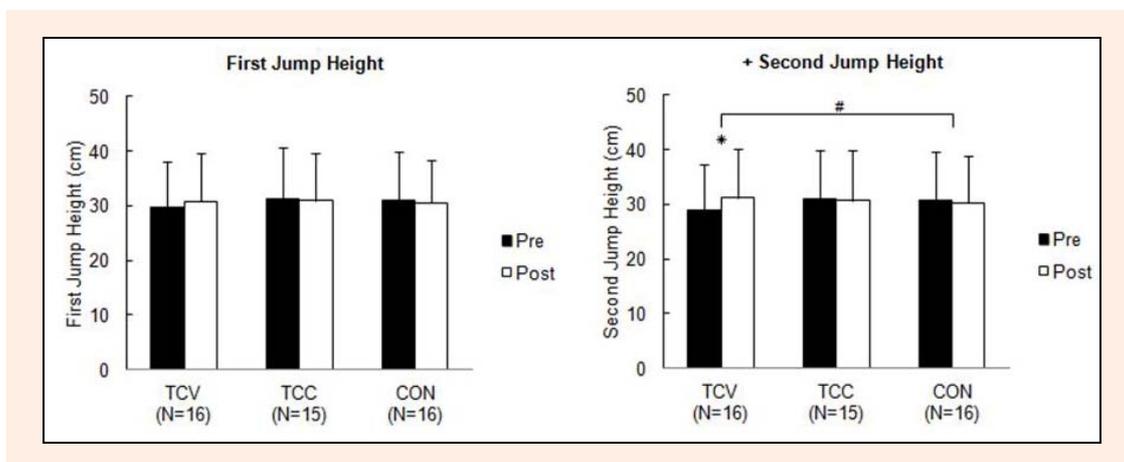


Figure 4. Mean and SD of jump height in TCV, TCC, and CON groups. **Left:** first jump; **Right:** second jump. # indicated that the posttraining value in the TCV group was significantly higher than the CON group after 8-weeks interventions. * indicated that significantly different between pre- and post- training values. + indicated that a significant interaction (group × time) effect (P < 0.05).

Previous studies demonstrated that repeated vibration stimuli could enhance neural adaptation (Abercromby et al., 2007; Lu and Kuo, 2003; Trans et al., 2009). This study was the first to explore the effect of Tai Chi Chuan combined with vibration training and used the moving area of the COP as an index for assessing balance control improvements during a static single leg stance with closed eyes. A larger moving area corresponds to a greater body sway. After eight weeks of training, the moving area of the TCV group was decreased by 15.3%, indicating that the combination of Tai Chi Chuan and high-frequency vibration stimuli enhanced balance control more efficiently within a shorter training period, when the TCC group only showed an improved trend as previous studies (Li et al., 2009; Xu et al., 2005). The moving area of the CON group increased by 24.4%, and a possible reason is a lack of physical activity because these participants were asked to abstain from their regular exercises for eight weeks, which may have decreased their balance control. The balance control related to daily activities, such as standing, walking, and going up and down stairs, and regular exercise can maintain or improve physical activity. Tai Chi Chuan also demonstrated a positive effect on balance control (Logghe et al., 2010; Low et al., 2009), and this study indicates that adding vibration stimuli during the Tai Chi Chuan movements can cause a significantly greater effect in eight weeks.

Although the activation of the knee flexor was not significantly different among the groups, with the exception of the CON group, the activation of both the knee extensor and flexor showed decreasing trends before and after training. The changes of activation in the knee extensor and flexor were analyzed by a surface EMG. It is presumed that in Tai Chi Chuan, while performing a continuous flexion and extension of the knee joint, vibration stimuli can enhance neuromuscular coordination and decrease the load on the knee extensor to delay muscle fatigue. Iwamoto et al. (2004) reported that receiving WBV training once a week for three months combined with static balance training consisting of a static single leg stance and resistance training could enhance the strength of the knee extensor and the duration of a static single leg stance in elderly females. Therefore, it is believed that a static single leg stance can enhance balance control and that resistance training can enhance the power of the knee extensor; additionally, after vibration stimuli excited the neuromuscular system, both balance control and muscle power were improved. In this study, after eight weeks of Tai Chi Chuan combined with vibration training, the participants could control their body sway with less muscle activation by better neuromuscular coordination.

Regarding lower extremity muscle power enhancement, this study showed that after eight weeks of Tai Chi Chuan combined with vibration training, the second jump height was significantly increased, and the activation of the knee extensor/flexor also was significantly decreased in the first jump. Because WBV training has become a safe and effective training method, a previous study showed that the acute effects of WBV training enhanced the vertical jump performance (Cardinale and Lim, 2003b; Gerodimos et al., 2010). Furthermore, two

serial studies reported that after four and eight months of chronic vibration training, the participants improved their vertical jump performance and leg extension strength, but their grip strength, sprint running, balance ability and bone density were unchanged (Torvinen et al., 2002; Torvinen et al., 2003). However, another study compared the effects of 12 weeks of WBV and resistance training in young women and found that the two types of training methods significantly increased the strength of the leg extensor, but only the WBV training significantly improved the vertical jump performance by 7.6% (Delecluse et al., 2003). In this study, the heights of two consecutive countermovement jumps were used as indexes for assessing the lower extremity muscle power. After eight weeks of training, the first jump height in the TCV group had not significantly changed, but the second jump height significantly increased by 8.14%, and both jump heights showed increasing trends comparing to the TCC and CON groups. After the first jump, the lower extremity muscle first generated eccentric contraction by landing and then progressed to concentric contraction immediately. Cardinale and Bosco (2003) proposed that vibration stimuli could effectively induce the reflex sensitivity of the muscle spindle, resulting in SSC. This study indicated that vibration stimuli improved the second jump performance more than the first jump by SSC, and there was no cross-interaction between the two different types of training methods.

The activation of the knee flexor and extensor in the first jump was significantly decreased by 36.1% and 10.2%, respectively. Although the first jump height in the TCV group was not significantly different from the other groups, the activation of the knee extensor and flexor was significantly decreased by the concentric contraction. These results indicated that participants in the TCV group completed the same level of performance more efficiently after training. For the two consecutive countermovement jumps, a reduction in the lower extremity muscle activation in the first jump would be advantageous for the second jump. Tai Chi Chuan requires performing continuous flexion and extension of the lower extremity joints in different directions, such that the muscles can progress through concentric and eccentric contractions repeatedly. In addition, vibration stimuli could effectively improve the effect of muscle power training, which increased the jump height and decreased the activation of the knee extensor and flexor.

Conclusion

This study indicated that performing eight weeks of Tai Chi Chuan and receiving vibration stimuli at 32 Hz together could improve balance control more efficiently for an untrained young population. Moreover, vibration stimuli during the Tai Chi Chuan movements continued the effects of WBV training on the lower extremity muscle power by SSC mechanism, and the same jump performance could be achieved with less muscle activation of the lower extremities. Consequently, the observation of this study was that combining two different types of training methods was more efficient and did not decrease the

overall training effects due to a cross-interaction. It is regarded as a safe, effective and efficient way to obtain significant training effects on balance control and lower extremity muscle power in a shorter term by performing the reformed Tai Chi Chuan routine on a vibration platform (size: 90×120 cm) with vibration stimuli at 32 Hz. Furthermore, the effects of Tai Chi Chuan combined with vibration stimuli at different intensities (frequency, peak-to-peak displacement and maximum acceleration) or for different populations could be explored in the future.

Acknowledgements

The authors would like to acknowledge Taiwan National Science Council (NSC 97-2622-B003-001-CC2) and Tonic Fitness Technology Inc. (MAGTONICTM) to provide the funding and the customized vibration platform. No competing interests in this study.

References

- Abercromby, A.F.J., Amonette, W.E., Layne, C.S., McFarlin, B.K., Hinman, M.R. and Paloski, W.H. (2007) Variation in neuromuscular responses during acute whole-body vibration exercise. *Medicine and Science in Sports and Exercise* **39**(9), 1642-1650.
- Cardinale, M. and Bosco, C. (2003) The use of vibration as an exercise intervention. *Exercise and Sport Sciences Reviews* **31**(1), 3-7.
- Cardinale, M. and Lim, J. (2003a) Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *Journal of Strength and Conditioning Research* **17**(3), 621-624.
- Cardinale, M. and Lim, J. (2003b) The acute effects of two different whole body vibration frequencies on vertical jump performance. *Medicina Dello Sport* **56**(4), 287-292.
- Cheung, W.H., Mok, H.W., Qin, L., Sze, P.C., Lee, K.M. and Leung, K.S. (2007) High-frequency whole-body vibration improves balancing ability in elderly women. *Archives of Physical Medicine and Rehabilitation* **88**, 852-857.
- Cochrane, D.J. and Stannard, S.R. (2005) Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *British Journal of Sports Medicine* **39**, 860-865.
- Delecluse, C., Roelants, M. and Verschueren, S. (2003) Strength increase after whole-body vibration compared with resistance training. *Medicine and Science in Sports and Exercise* **35**(6), 1033-1041.
- Eklund, G. and Hagbarth, K.E. (1966) Normal variability of tonic vibration reflexes in man. *Experimental Neurology* **16**(1), 80-92.
- Fagnani, F., Giombini, A., Cesare, A., Pigozzi, F. and Salvo, V. (2006) The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. *American Journal of Physical Medicine and Rehabilitation* **85**(12), 956-962.
- Fong, S.M. and Ng, G.Y. (2006) The effects on sensorimotor performance and balance with Tai Chi training. *Archives of Physical Medicine and Rehabilitation* **87**, 82-87.
- Gerodimos, V., Zafeiridis, A., Karatrantou, K., Vasilopoulou, T., Channou, K. and Pispirikou, E. (2010) The acute effects of different whole-body vibration amplitudes and frequencies on flexibility and vertical jumping performance. *Journal of Science and Medicine in Sport* **13**(4), 438-443.
- Giminiani, R.D., Tihanyi, J., Safar, S. and Scrimaglio, R. (2009) The effects of vibration on explosive and reactive strength when applying individualized vibration frequencies. *Journal of Sports Sciences* **27**(2), 169-177.
- Hermens, H.J., Freriks, B., Disselhorst-Klug, C. and Rau, G. (2000) Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography Kinesiology* **10**(5), 361-374.
- Hong, Y., Li, J.X. and Robinson P.D. (2000) Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *British Journal of Sports Medicine* **34**, 29-34.
- Iwamoto, J., Otaka, Y., Kudo, K., Takeda, T., Uzawa, M. and Hirabayashi, K. (2004) Efficacy of training program for ambulatory competence in elderly women. *The Keio Journal of Medicine* **53**(2), 85-89.
- Kvorning, T., Bagger, M., Caserotti, P. and Madsen, K. (2006) Effects of vibration and resistance training on neuromuscular and hormonal measures. *European Journal of Applied Physiology* **96**, 615-625.
- Li, J.X., Xu, D.Q. and Hong, Y. (2009) Changes in muscle strength, endurance, and reaction of the lower extremities with Tai Chi intervention. *Journal of Biomechanics* **42**(8), 967-971.
- Linthornes, N. (2001) Analysis of standing vertical jumps using a force platform. *The American Journal of Physiology* **69**(11), 1198-1204.
- Logghe, I.H.J., Verhagen, A.P., Rademaker, A.C.H.J., Bierma-Zeinstra, S.M.A., van Rossum, E., Faber, M.J. and Koes, B.W. (2010) The effects of Tai Chi on fall prevention, fear of falling and balance in older people: A meta-analysis. *Preventive Medicine* **51**, 222-227.
- Lorenzen, C., Maschette, W., Koh, M. and Wilson, C. (2009) Inconsistent use of terminology in whole body vibration exercise research. *Journal of Science and Medicine in Sport* **12**, 676-678.
- Low, S., Ang, L.W., Goh, K.S. and Chew, S.K. (2009) A systematic review of the effectiveness of Tai Chi on fall reduction among the elderly. *Archives of Gerontology and Geriatrics* **48**(3), 325-331.
- Lu, W.A. and Kuo, C.D. (2003) The effect of Tai Chi Chuan on the autonomic nervous modulation in older persons. *Medicine and Science in Sports and Exercise* **35**(12), 1972-1976.
- Luo, J., Mcnamara, B. and Moran, K. (2005) The use of vibration training to enhance muscle strength and power. *Sports Medicine* **35**(1), 23-41.
- Luo, J., Mcnamara, B. and Moran, K. (2008) Effect of vibration training on neuromuscular output with ballistic knee extensions. *Journal of Sports Sciences* **26**(12), 1365-1373.
- Mak, M.K. and Ng, P.L. (2003) Mediolateral sway in single leg stance is the best discriminator of balance performance for Tai-Chi practitioners. *Archives of Physical Medicine and Rehabilitation* **84**, 683-686.
- Marín, P.J., Martín-López, A., Vicente-Campos, D., Angulo-Carrere, M.T., García-Pastor, T., Garatachea, N. and Chicharro, J.L. (2011) Effects of vibration training and detraining on balance and muscle strength in older adults. *Journal of Sports Science and Medicine* **10**, 559-564.
- Marín, P.J. and Rhea, M.R. (2010a) Effects of vibration training on muscle strength: a meta-analysis. *Journal of Strength and Conditioning Research* **24**(2), 548-556.
- Marín, P.J. and Rhea, M.R. (2010b) Effects of vibration training on muscle power: a meta-analysis. *Journal of Strength and Conditioning Research* **24**(3), 871-878.
- Mikhael, M., Orr, R. and Singh, M.A.F. (2010) The effect of whole body vibration exposure on muscle or bone morphology and function in older adults: A systematic review of the literature. *Maturitas* **66**(2), 150-157.
- Mischi, M. and Cardinale, M. (2009) The Effects of a 28-Hz vibration on arm muscle activity during isometric exercise. *Medicine and Science in Sports and Exercise* **41**(3), 645-652.
- Moran, K., Mcnamara, B. and Luo, J. (2007) Effect of vibration training in maximal effort (70% 1RM) dynamic bicep curls. *Medicine and Science in Sports and Exercise* **39**(3), 526-533.
- Osawa, Y. and Oguma, Y. (2011) Effects of whole-body vibration on resistance training for untrained adults. *Journal of Sports Science and Medicine* **10**, 328-337.
- Rehn, B., Lidstrom, J., Skoglund, J. and Lindstrom, B. (2007) Effects on leg muscular performance from whole-body vibration exercise: A systematic review. *Scandinavian Journal of Medicine and Science in Sports* **17**(1), 2-11.
- Rønnestad, B.R. (2004) Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *Journal of Strength and Conditioning Research* **18**(4), 839-845.
- Taylor, A.H., Cable, N.T., Faulkner, G., Hillsdon, M., Narici, M. and Van Der Bij, A.K. (2004) Physical activity and older adults: a review of health benefits and the effectiveness of interventions. *Journal of Sports Sciences* **22**(8), 703-725.
- Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T.A.H., Pasanen, M., Kontulainen, S., Jarvinen, T.L.N., Jarvinen, M., Oja, P. and Vuori, I. (2002) Effect of four-month vertical whole body vibration on performance and balance. *Medicine and Science in Sports and Exercise* **34**(9), 1523-1528.

- Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T.A.H., Pasanen, M., Kontulainen, S., Nenonen, A., Jarvinen, T.L.N., Paakkala, T., Jarvinen, M and Vuori, I. (2003) Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: A randomized controlled study. *Journal of Bone and Mineral Research* **18**(5), 876-884.
- Trans, T., Aaboe, J., Henriksen M., Christensen, R., Bliddal, H. and Lund, H. (2009) Effect of whole body vibration exercise on muscle strength and proprioception in females with knee osteoarthritis. *The Knee* **16**(4), 256-261.
- Tsang, W.W.N. and Hui-Chan, C.W.Y. (2004) Effect of 4- and 8-wk intensive Tai Chi training on balance control in the elderly. *Medicine and Science in Sports and Exercise* **36**(4), 648-657.
- Tsang, W.W., Wong, V.S., Fu, S.N. and Hui-Chan, C.W. (2004) Tai Chi improves standing balance control under reduced or conflicting sensory conditions. *Archives of Physical Medicine and Rehabilitation* **85**, 129-137.
- Wilcock, I.M., Whatman, C., Harris, N. and Keogh, J.W.L. (2009) Vibration training: could it enhance the strength, power, or speed of Athletes? *Journal of Strength and Conditioning Research* **23**(2), 593-603.
- Wu, G. (2002) Evaluation of the effectiveness of Tai Chi for improving balance and preventing falls in the older population-a review. *Journal of the American Geriatrics Society* **8**, 746-754.
- Wu, G., Zhao, F., Zhou, X. and Wei, L. (2002) Improvement of isokinetic knee extensor strength and reduction of postural sway in the elderly from long-term Tai Chi exercise. *Archives of Physical Medicine and Rehabilitation* **83**, 1364-1369.
- Xu, D., Hong, Y., Li, J. and Chan, K. (2004) Effect of Tai Chi exercise on proprioception of ankle and knee joints in old people. *British Journal of Sports Medicine* **38**, 50-54.
- Xu, D.Q., Li, J.X. and Hong, Y. (2005) Effect of regular Tai Chi and jogging exercise on neuromuscular reaction in older people. *Age and Ageing* **34**(5), 439-444.

Key points

- Eight weeks of Tai Chi Chuan combined with vibration training can more efficiently improve balance control for an untrained young population.
- The positive training effect on the lower extremity muscle power induced by vibration stimuli during Tai Chi Chuan movements still remains significant because of SSC mechanism.
- Combining Tai Chi Chuan with vibration training is more efficient and does not decrease the overall training effects due to a cross-interaction of each other.

AUTHORS BIOGRAPHY



Pao-Hung CHUNG

Employment

Assistant Professor, Graduate Institute of Sports Equipment Technology, Taipei Physical Education College, Taipei, Taiwan

Degree

Ph.D. Candidate

Research interest

Sports engineering and sports equipment development

E-mail: pchungtw@gmail.com



Guan-Lun LIN

Employment

Master of Science, Graduate Institute of Exercise and Sports Science, National Taiwan Normal University, Taipei, Taiwan

Degree

MSc

Research interest

Sports science

E-mail: uvision0217@gmail.com



Chiang LIU

Employment

Professor, Graduate Institute of Sports Equipment Technology, Taipei Physical Education College, Taipei, Taiwan

Degree

PhD

Research interest

Sports training and baseball science

E-mail: chiangliu1974@yahoo.com.tw



Long-Ren CHUANG

Employment

Associate Professor, Department of Chinese Martial Arts, Chinese Culture University, Taipei, Taiwan

Degree

PhD

Research interest

Chinese martial arts and Tai Chi Chuan

E-mail: allen@faculty.pccu.edu.tw



Tzyy-Yuang SHIANG

Employment

Distinguished Professor, Graduate Institute of Exercise and Sports Science, National Taiwan Normal University, Taipei, Taiwan

Degree

PhD

Research interest

Biomechanics and sports medicine

E-mail: tyshiang@gmail.com

✉ Dr. Tzyy-Yuang Shiang

Graduate Institute of Exercise and Sports Science, National Taiwan Normal University, No. 88, Sec. 4, Ting-Zhou Rd., Wen-Shan District, Taipei City 11677, Taiwan