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PLEASE CITE THE PUBLISHED VERSION

https://doi.org/10.1080/15438627.2021.2020788

PUBLISHER

Taylor & Francis (Routledge)

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

This is an Accepted Manuscript of an article published by Taylor & Francis in Research in Sports Medicine on 26 Dec 2021, available online: https://doi.org/10.1080/15438627.2021.2020788

Muscle co-contraction and pre-activation in knee and ankle joint during a typical Tai Chi brush-knee twist-step

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Abstract

This study aimed to investigate the co-contraction and pre-activation of agonistic and antagonistic muscles in experienced Tai Chi (TC) practitioners during normal walking (NW) and brush-knee twist-step (BKTS). The electromyographic activities of rectus femoris, biceps femoris, and tibialis anterior and lateral gastrocnemius muscles were collected during BKTS and NW in 28 TC practitioners. The pre-activation of knee and ankle joints before initial landing of left foot, and the co-contraction of knee and ankle joint in double-stance phase I (DSI), single-stance phase (SS), double-stance phase II (DSII), and swing phase (SW) were calculated during BKTS and NW. Ankle co-contraction significantly increased during DSI and SS in BKTS movements than compared with that in NW. For DSI and SW, SS and DSII, and DSII and SW, a significant difference was found in BKTS. The pre-activation of knee joint significantly decreased in BKTS and NW. This study indicated greater ankle joint muscle co-contraction in DSI and SS of stance phase and lower knee joint muscle co-contraction and pre-activation than in NW in BKTS movement. In addition, greater ankle joint muscle co-contraction was observed in the DSI, SS, and DSII of stance phase than those of swing phase in BKTS movement.

Keywords: Tai Chi; brush-knee twist-step; normal walking; co-contraction; pre-activation.

Introduction

Tai Chi (TC) is one of the most popular exercise forms among the elderly. Studies have shown that the muscle activation of knee and ankle joints improved significantly during Tai Chi movements in the elderly (Tseng, 2007, Wu, 2008). For example, ankle dorsiflexors and knee extensors were activated significantly longer and higher during TC Parting the Wild Horse's Mane movement than normal walking (NW) (Wu, 2008). The peak values of root-mean-square (RMS) in quadriceps were significantly greater in TC stepping than in NW (Tseng, 2007). However, most studies only examined the levels of activation of lower limb muscles during TC movements, and the coupling characteristics of agonistic and antagonistic muscles are lacking (Gatts, 2008, Tseng et al., 2007, Wu, 2008, Wang et al., 2017).

Muscle co-contraction and pre-activation, defined as the simultaneous activation of agonist and antagonist muscles (Wayn et al., 2021), is a common clinical measure to understand the effects of aging and pathology on muscle control strategies (Chandran et al., 2019, Souissi et al., 2017). The lower extremities' pre-activation and co-contraction increased with aging in the elderly (Lo et al., 2017, Serpell et al., 2014). Vette et al. (2017) reported that the co-contraction time in ankle joint is longer during quiet standing in the elderly than in young people. Chandran et al. (2019) reported that the elderly showed greater knee muscle co-contraction on the swing phase during stair walking than young adults. The increased co-contraction or pre-activation of knee and ankle joint has been indicated as a strategy to compensate for the decreased postural control and sensory processing in the elderly (Lo et al., 2017, Serpell et al., 2014, Chandran et al., 2019). Although muscle co-contraction and pre-activation, as a key clinical pathological parameter, have been widely used to assess neuromuscular control strategies in elderly, the lower-limb muscle co-contraction and pre-activation during TC movements remain unknown.

Brush-knee twist-step (BKTS) is one of the basic and common specific typical movements in various TC styles, such as 24-, 48-, and 96-form. In the previous research, the BKTS movement showed a greater increase in the range of motion, lower increase in joint loading, strong muscle activity in the knee and ankle joint (Zhu et al., 2021, Li et al., 2019). Pressure contact stress is much more concentrated in the knee and generally less in the ankle joint (Li et al., 2019). However, the pre-activation and co-contraction of knee joint and ankle joint during BKTS movement is unknown. NW is the most common gait pattern in daily activities among the population. BKWS and NW gait are kind of cyclic motion, and they have well-defined phases, such as double-leg stance, single-leg stance, and swing (Li et al., 2019). Therefore, the present study aimed to investigate agonist and antagonist muscles coupling control with electromyography (EMG) in knee and ankle joints of BKTS in comparison with NW in experienced practitioners. The hypotheses were as follows: 1) pre-activation and co-contraction were significantly lower in knee and ankle joint in BKTS than in NW and 2) significant difference in knee and ankle co-contraction is present among four stages of gait cycle during BKTS.

Method

Participants

Sample-size estimation was conducted with G*Power software. The co-contraction for BF was 11.42% ± 7.37% in TC gait and 8.28% ± 4.31% in NW (Tseng et al., 2007). The effect size and estimated required sample sizes were calculated to be 0.49 and 28, respectively, by setting the significance level to 0.05 and the statistical power to 0.08 in a one-tailed test on matched pairs. Twenty-eight healthy elderly individuals (male/female: 13/15; height: 161.0 ± 6.6 cm; age: 66.8 ± 5.9 years; weight: 61.6 ± 9.3 kg; and practice duration: 12.8 ± 5.5 years), who regularly exercised long-term TC for 60 min per day three times a week for at least 10 years, participated in this study. The exclusion criteria included the inability to follow instructions, unstable heart conditions, and joint replacements in the lower extremities, arthritis, diabetes, visual deficits, vestibular deficits, or any type of neuromuscular problems that could prevent participants from meeting the project requirements. All participants signed approved informed consent forms prior to participation. This study was approved by Shandong Sport University Research Ethics Board.

Equipment

A 12-camera Vicon motion capture system (UK) with a sample frequency of 100 Hz was used to capture lower-extremity motion data. Two force plates (Kistler, Switzerland) with a sample frequency of 1000 Hz were used to measure the foot–floor contact events of both feet during a complete movement cycle. Surface EMG (Noraxon, USA) with a sample frequency of 2000 Hz and silver/silver chloride bipolar-surface EMG electrodes (Cathay Manufacturing Corp.) were used to record the muscle activities of the rectus femoris, biceps femoris, tibialis anterior muscle, and lateral head of the gastrocnemius in accordance with SENIAM guidelines (Hermens, et al.,2000). The surface of each electrode (20 mm in diameter) contained a gel-like substance to ensure the EMG signal's conduction quality.

Procedure

Kistler force plate, Vicon motion system, and electromyography (Noraxon Myosystem) were used collect kinetic, kinematic, and muscle activity data, respectively. All three measurements were synchronized with Nexus Software. Forty-one reflective markers with a diameter of 14 mm were pasted on the participant's skin or clothes. After the participant's skin was prepared (shaving, gently scrubbing, and cleaning with alcohol), bipolar surface electrodes were placed over the motor point of each muscle on the left leg (Wu & Ren, 2009). Before testing, each participant was used to practice BKTS continuously for 5 min. Force plates were placed along a 10 m walkway for two consecutive initial foot contacts of the participant's left foot to land on the plates during the test. The participants were asked to stand at the starting position and begin BKTS at a self-determined speed. The participants repeated a minimum of six trials each for TC and walk gait. They were given 3 min of rest between trials.

Data processing

BKTS is composed of symmetrical movements, and it starts from the left side of the ground through one complete cycle; therefore, only the left foot was selected for analysis in the present study (Wu & Ren, 2009). The complete cycle of BKTS is shown in Fig. 1. The movement has a stance phase and a swing phase for left foot–floor contact, both of which were marked by consecutive left heel strike and left toe off events.

BKTS and NW were divided into the following stages in accordance with the gait cycle: double-stance phase I (DSI), single-stance phase (SS), double-stance phase II (DSII), and swing phase (SW) (Wu, 2008). DSI is from left foot landing to right foot take-off, SS is from right foot take-off to right foot landing, DSII is from right foot landing to left foot take-off, and SW is from left foot take-off to left foot landing. The original raw EMG signal was band-pass filtered at a range of 10–200 Hz, and the signal was full-wave rectified. The RMS amplitude of the signal was computed using a 50 ms window (Chen et al., 2011). The movement was regularized to the peak EMG value within the maximum isometric contraction of each muscle over all trials as a percentage (Chan et al., 2003). Finally, the average EMG activity of each muscle was calculated.

The parameters analyzed in this study included the phase-standardized muscle co-activation of the rectus femoris, biceps femoris, tibialis anterior muscle, and lateral head of gastrocnemius 50 ms before the start of movements and the co-contraction of the movements in the four phases. The specific calculation method is as follows: (1) Pre-activation refers to the simultaneous activity of muscles around the joint. The calculation formula is as follows (Serpell et al., 2014):

$$\mathrm{RMS} = \left(1/\mathrm{T}\int_{t1}^{t2} \mathrm{EMG}^2(t)dt\right)^{1/2} \quad (1)$$

$$\text{Pre-activation} = \text{RMSantagonist muscle}/\text{RMSagonistic muscle} \times 100\% \quad (2)$$

(2) Co-contraction reflects the antagonist muscles during joint active contraction and the coordination function between agonist and antagonist muscles. The calculation formula is as follows (Iwamoto et al., 2017):

$$\mathrm{IEMG}=\int_{t1}^{t2} \mathrm{EMG}(t)\, dt \quad (1)$$

$$\text{Co-contraction} = \frac{\text{IEMGantagonist muscle}}{\text{IEMGagonistic muscle} + \text{IEMGantagonist muscle}} \times 100\% \quad (2)$$

Statistical analysis

All data were presented as mean and standard deviation. Shapiro–Wilk test was used for normal distribution test. Two-way multivariate ANOVA (gait type × phase) with repeated measures (MANOVA) was conducted on the co-contraction. If a significant interactive effect was found, the Bonferroni test was used for post-hoc analysis. Otherwise, an ANOVA on each main effect was conducted. Paired t-test was conducted on the pre-activation between BKTS and NW gait. Statistical significance was set at $P < 0.05$, 95% confidence interval (CI) was determined, and the effect size was expressed as η^2. Small effect denotes $0.001 \leq \eta^2 < 0.06$, moderate effect refers to $0.06 \leq \eta^2 < 0.14$, and large effect means $\eta^2 \geq 0.14$. All statistics were performed using IBM SPSS 20.0 software (version 20.0, Chicago, IL, United States).

Results

In Figure 2, the two-way MANOVA showed a significant interaction effect in ankle co-contraction ($F = 4.035$, $P = 0.008$, and $\eta^2 = 0.053$). The post-hoc statistical results showed that the ankle co-contraction significantly increased during DSI ($P = 0.005$ and 95% CI = 0.047–0.268) and SS ($P = 0.010$ and 95% CI = 0.036–0.257) in BKTS movements compared with those in NW. For DSI and SW ($P = 0.019$ and 95% CI = 0.016–0.277), SS and DSII ($P < 0.001$ and 95% CI = 0.080–0.341), and DSII and SW ($P = 0.015$, 95% CI = 0.020–0.2807), a significant difference was found in BKTS.

In Figure 3, the two-way MANOVA showed no significant interaction effect ($P = 0.168$ and $\eta^2 = 0.023$) and significant movement effect ($F= 29.424$, $P < 0.001$, and $\eta^2= 0.120$) in knee joint co-contraction.

In Figure 4, the paired t-test showed that the pre-activation of knee joint significantly decreased ($P < 0.001$, 95% CI = from −2.38 to −0.0862), and no significant difference was observed in the pre-activation of ankle joint (P = 0.384 and 95% CI = from −0.601 to 1.497) between BKTS and NW.

Discussion

This study aimed to investigate the coupling characteristics of agonistic and antagonistic muscles of the lower extremity joint in experienced TC practitioners during NW and BKTS. This study is the first to quantitatively illustrate the muscle co-contraction and pre-activation in ankle and knee joint during BKST in TC practitioners. The results partially supported the first hypothesis that the co-contraction and pre-activation levels of the knee joint in BKTS decreased compared with those in NW.

In this study, the levels of co-contraction and pre-activation of the knee joint in BKTS decreased compared with those in NW, inconsistent with the results of a previous study. The co-contraction and pre-activation levels of agonist and antagonist muscles may improve joint stability and promote reasonable distribution of force around the joint (Dashti Rostami et al., 2020, Hu et al., 2020, Zhang et al., 2021). Chandran et al. (2019) and Wayne et al. (2021) found that lifting, forward propulsion, and lowering the foot demand more cognitive resources during BKTS in Tai Chi beginners, and they could strengthen muscle co-contraction and pre-activation and stiffen joint stability for compensating poor postural control ability (Chandran et al., 2019, Wayne et al., 2021). The possible reason may be that among the selected participants, one is a TC beginner in a previous study, and the other is a long-term TC practitioner in the present study. The experienced TC practitioners could relatively increase activity levels at knee extensor muscles and decrease activity levels at knee flexors muscles (Tseng et al., 2007, Wu et al., 2004). The increase in TC experience via learning and practice continuously decreased co-contraction patterns and developed efficient, healthy muscle activation patterns of only activating agonist muscles with less activation in antagonist muscles (Tseng et al., 2007). The peak muscle activity levels were also moved into stable and optimal levels, which were around the minimal requirements of activity demands (Tseng et al., 2007).

Interestingly, the results showed that the levels of co-contraction in ankle joint during BKTS significantly increased compared with those during NW, DSI, and SS, which do not support the second hypothesis. Greater co-contraction of the ankle joint indicated that the elderly may increase ankle joint muscle contraction for completing TC BKTS movements. Three factors may lead to these results. First, the body weight is fairly evenly distributed between the fore-foot and rear-foot regions during TC, and the foot COP is centered in the mid-foot region, especially during the single stance phase, which may require the lower extremities to recruit more muscles that contract at a higher level than in NW (Wu et al., 2004, 2005). Second, TC movements presented a significantly larger maximum joint moment in eversion/inversion and external/internal rotation in the ankle joint than NW, suggesting that the ankle muscles were highly activated and worked intensively (Li, et al., 2018). Third, TC has sustained large joint range of motions in the lower extremity, especially for ankle dorsiflexion, and it may activate more ankle dorsiflexors at a higher level and over a longer duration during TC than during NG (Wu et al., 2004).

A notable detail that the participants showed greater ankle joint muscle co-contraction in the DSI, SS, and DSII of stance phase that those of swing phase in BKTS movement. To the best of the authors' knowledge, this study is the first to report muscle co-contraction during the swing phase and stance phase of TC BKTS movements. First, compared with swing phase, better postural stability control of lower limb is needed during stance phase, which may require more cognitive resources and muscle activation (Chandran et al., 2019). Higher co-contraction of ankle joint could improve the stability of lower limb joints (Lo et al., 2017). Second, higher co-contraction levels during the swing phase of the gait cycle were associated with poorer executive function (Lo et al., 2017). However, no significant difference was found in the co-contraction of ankle joint between stance and swing phases during NW, inconsistent with the results of a previous study (Chandran et al., 2019). In addition, the elderly displayed greater muscle co-contractions during swing phase (Chandran et al., 2019). The discrepancy may be attributed to different levels of cognitive and motor activations between two motion controls, normal walking in this study and stair walking in a previous study. Stair walking is more difficult than NW, and it may require more activation for motor control during swing phase to prevent falls in the elderly (Peng, et al., 2016). Thus, in future studies, the stance and swing phases of the gait cycle should be considered independently when measuring lower limb muscle cocontraction during walking.

This study has three limitations. First, only four muscles activities were recorded with sEMG. Further studies should explore more muscles of lower limbs during TC movements. Second, co-contraction and pre-activation were assessed in one TC movement, "brush-knee twist-step," and more TC typical movements should be quantified in the future. Third, this study is a cross-section study. Longitudinal intervention could be conducted for investigating the effect of regular TC exercise on the co-contraction and pre-activation of lower limbs.

Conclusion

In this study，the co-contraction and pre-activation in ankle and knee joints during Tai Chi BKTS movements were quantified. The results demonstrated that BKTS has greater ankle joint co-contraction during the DSI and SS stages of stance phase than NW and decreased knee joint co-contraction/pre-activation in TC practitioners. Ankle joint muscle co-contraction is greater during the DSI, SS, and DSII stages of stance phase than that in swing phase in BKTS movement. Future work should focus on the effect of regular TC exercise on the co-contraction and pre-activation of lower extremities and explore the neuromuscular control mechanism for preventing falls.

Disclosure statement

No potential conflict of interest was reported by the authors.

Acknowledgement

This study was supported by Shandong Provincial Natural Science Foundation (ZR2020QC091), the grant of the funding of Youth Fund Project of Research Planning Foundation on Humanities and Social Sciences of the Ministry of Education (19YJC880083, 20YJCZH001), China Shandong Key Research and Development Plan (2019GSF108211).

Figure legends

Figure 1. Illustration of a complete cycle of "BKTS" and "NW" (A: brush-knee twist-step; B: normal walking).

Figure 2. Comparison of knee joint co-contraction in four phases between the BKWS and NW(Mean±SD).

Figure 3. Comparison of ankle joint co-contraction in four phases between the BKWS and NW (Mean±SD).▲, significant difference compared with swing phase, $p<0.05$.*, significant difference between the BKWS and NW.

Figure 4. Comparison of the pre-activation of knee and ankle joint between the BKWS and NW (Mean±SD). *, significant difference between the BKWS and NW, $p<0.05$.

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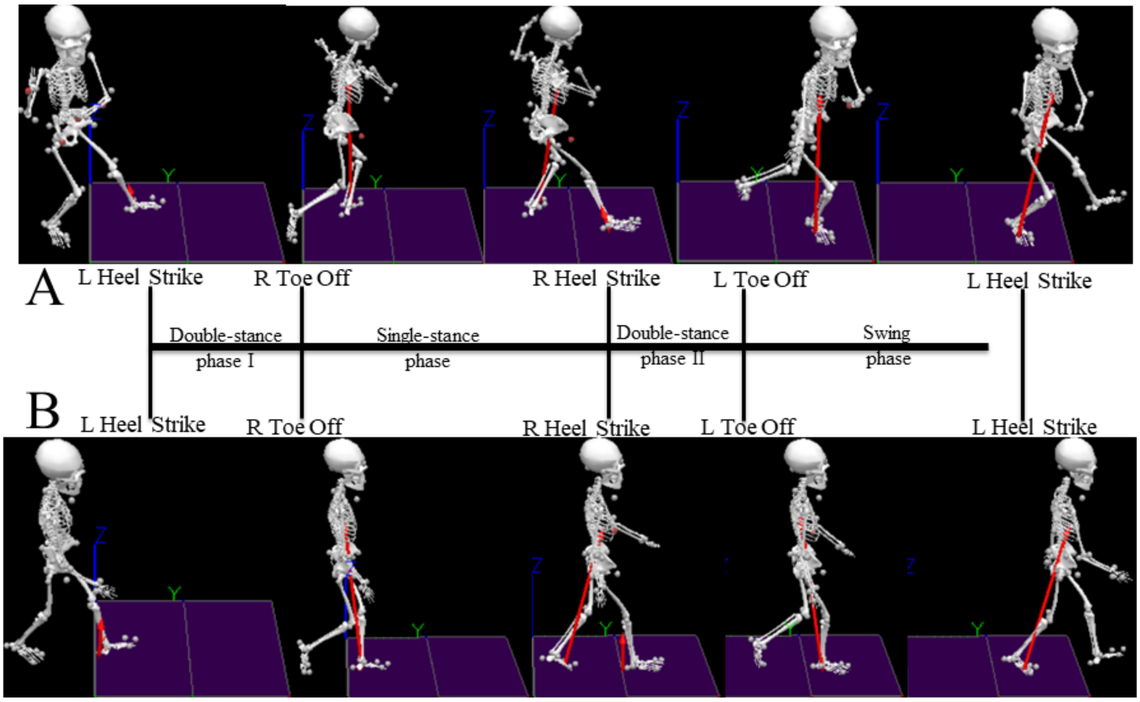
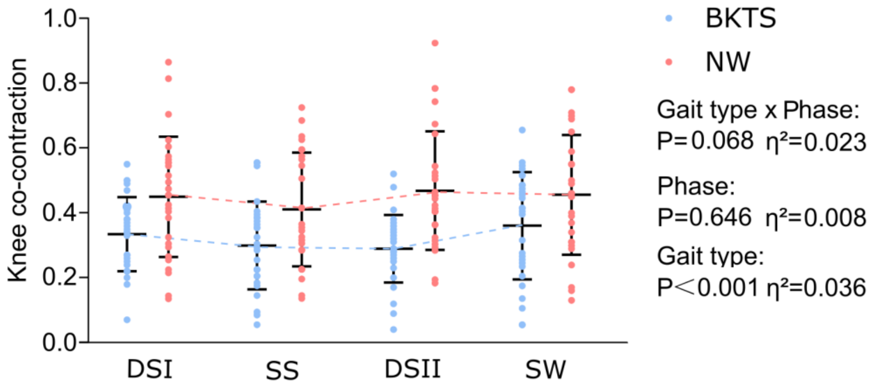
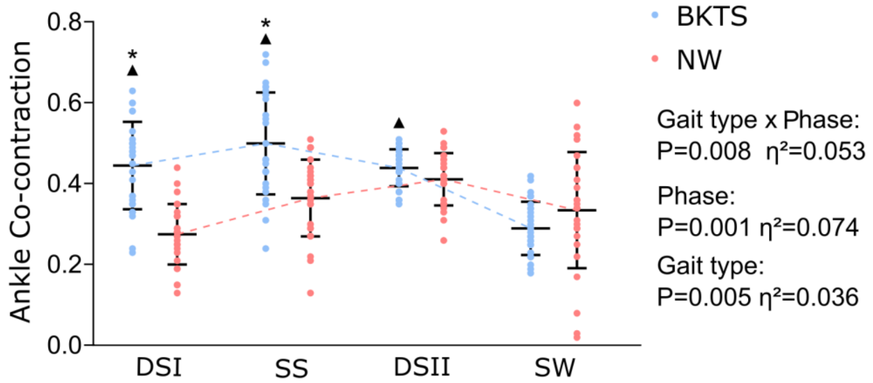
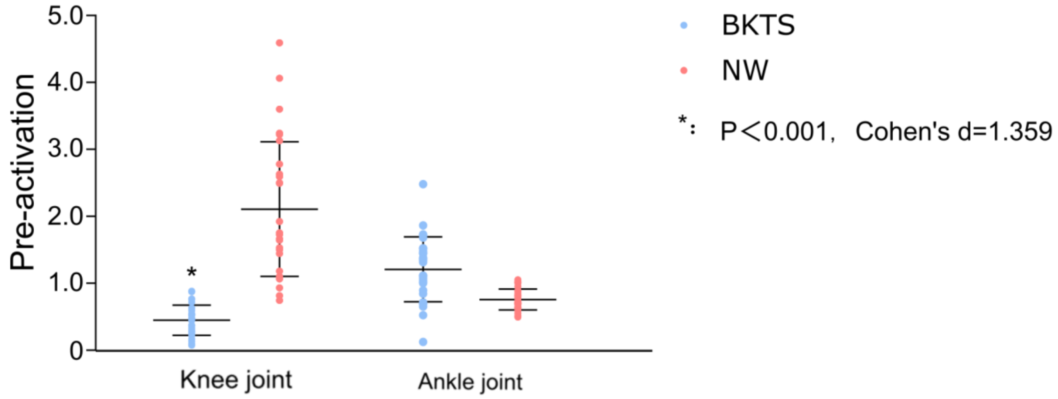




1.0
0.8
0.6
0.4
0.2
0.0
Knee co-contraction
DSI
SS
DSII
SW
BKTS
NW
Gait type x Phase:
P=0.068 η²=0.023
Phase:
P=0.646 η²=0.008
Gait type:
P＜0.001 η²=0.036



0.8
0.6
0.4
0.2
0.0
Ankle Co-contraction
DSI
SS
DSII
SW
BKTS
NW
Gait type x Phase:
P=0.008 η²=0.053
Phase:
P=0.001 η²=0.074
Gait type:
P=0.005 η²=0.036



5.0
4.0
3.0
2.0
1.0
0
Pre-activation
Knee joint
Ankle joint
BKTS
NW
*: P＜0.001, Cohen's d=1.359