Research in Sports Medicine
An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gspm20

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To cite this article: Teng Zhang, Min Mao, Wei Sun, Li Li, Yan Chen, Cui Zhang, Xinyan Zhang & Qipeng Song (2021): Effects of a 16-week Tai Chi intervention on cutaneous sensitivity and proprioception among older adults with and without sensory loss, Research in Sports Medicine, DOI: 10.1080/15438627.2021.1906673

To link to this article: https://doi.org/10.1080/15438627.2021.1906673

Published online: 28 Mar 2021.

RESEARCH IN SPORTS MEDICINE
https://doi.org/10.1080/15438627.2021.1906673

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Effects of a 16-week Tai Chi intervention on cutaneous sensitivity and proprioception among older adults with and without sensory loss

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Abstract

This study investigated the effects of a 16-week Tai Chi (TC) intervention on cutaneous sensitivity and proprioception among older adults with and without sensory loss. Thirty-six older adults were divided into sensory loss and control groups, and they underwent a 16-week TC intervention. Significant interactions were detected in heel cutaneous sensitivity (p = 0.046, F = 4.419) and knee flexion (p = 0.043, F = 4.580), extension (p = 0.027, F = 5.529) and ankle plantar-flexion proprioception (p = 0.037, F = 4.860). The post hoc test indicated that in the sensory loss group, heel cutaneous sensitivity threshold (p = 0.034) and knee flexion (p = 0.004), extension (p = 0.002) and ankle plantar-flexion (p = 0.023) proprioception threshold decreased at week 17, whereas in the control group, knee flexion (p = 0.029) proprioception threshold decreased at week 17. TC intervention improved cutaneous sensitivity at more sites and proprioception in more joints among the older adults with sensory loss. TC intervention is a good option for older adults to exercise, and it is more effective among older adults with sensory loss.

ARTICLE HISTORY
Received 26 December 2020
Accepted 15 March 2021

KEYWORDS
Kinaesthesia; monofilaments; peripheral neuropathy; plantar sensitivity; Tai Chi Chuan

Introduction

Sensory loss is an early symptom of peripheral neuropathy (PN), which has a prevalence of more than 15% among the older adults over 65 years old (Gregg et al., 2004). Peripheral nerve endings, axons and myelin of peripheral nerves in people with sensory loss are damaged in a distal to proximal manner, and this deterioration commonly leads to reduced sensation (Crone & Krarup, 2013). The gait instability among PN could be due to age-related decline of foot cutaneous sensation (Pratorius et al., 2003), which provides detailed spatial and temporal information about foot contact pressure, and may provide several types of information to promote the control of the compensatory stepping response (Pratorius et al., 2003). Those

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with sensory loss have a higher risk of falls, which has been shown to be a major global cause of mortality among the older adults (Machado et al., 2017). The cutaneous sensitivity is different between foot sole sites, due to the notable differences in cutaneous receptor distribution and firing characteristics (Kennedy & Inglis, 2002), and the mechanical properties of the skin, like its hardness and thickness (Strzalkowski et al., 2015). Different studies used different numbers of plantar sites to represent cutaneous sensitivity, e.g. one site (Handrigan et al., 2012), three sites (Karim et al., 2019) or five sites (Strzalkowski et al., 2015). Five-site detection has a higher specificity, compared with one- to three-site detections, and could avoid wasting time, compared with 8- to 10-site detections (Baraz et al., 2014).

Researchers indicated that lower extremity strength was not related to balance control in individuals with PN (Manor & Li, 2009), and older adults relied primarily on cutaneous and proprioceptive input to maintain balance (Li et al., 2019). Proprioception is the perception of limb movement and spatial orientation generated by body stimulation, which plays a crucial role in maintaining joint stability (Katharina et al., 2015). Proprioception is essential for the older adults with sensory loss, as the older adults compensate for the loss of cutaneous inputs by using proprioception more than vestibular and visual cues (Katharina et al., 2015). Many studies investigated the effect of physical exercise on the ankle joint proprioception among the older adults (Zhang et al., 2015), while limited studies investigated the effects of exercise on knee joint proprioception (Tsang & Hui-Chan, 2003), although the knee joint is the body's main stable support joint. In addition, studies investigated the effects of physical exercise on multi-joint proprioception are lacking.

There is currently a lack of effective clinical methods to treat age-related sensory loss or PN. Tai Chi (TC) intervention may be an option because previous studies have suggested that practising TC could reduce the risk of falls by improving cutaneous sensitivity (Li & Manor, 2010) and proprioception (Zhang et al., 2015) among the older adults. When sensory loss occurs, peripheral nerves may have undergone morphological changes, such as axonal loss and demyelination (Crone & Krarup, 2013). In this regard, the effects of TC intervention on cutaneous sensitivity and proprioception may be different among older adults with or without sensory loss.

People with sensory loss have a higher risk of falls (Machado et al., 2017). A few reports demonstrated improved sensation following non-surgical intervention (Hackney & Earhart, 2008). Investigating the effects of TC intervention on cutaneous sensitivity and proprioception among the older adults with and without sensory loss can provide new insights into preventing falls among this vulnerable population. This study aims to evaluate the effects of TC intervention on cutaneous sensitivity and proprioception among the older adults with and without sensory loss. It is hypothesized that after ① TC intervention could improve cutaneous sensitivity, and more sites would be improved among older adults with sensory loss; ② TC intervention could improve proprioception, and more joints would be improved among older adults with sensory loss.

Materials and Methods

Participants

Forty-seven older adults were recruited by distributing flyers and providing presentations in the local community. The inclusion criteria are 1) aged 65 years and older and 2) no TC intervention experience. The exclusion criteria are 1) self-reported history or evidence of central nervous system dysfunction, 2) self-reported trauma or disease that might significantly affect gait or postural control, 3) evidence of foot sole ulcers or cardiac pacemaker and 4) global cognitive impairment defined by a Mini-Mental State Exam (MMSE) score of <24. Thirty-six participants met the criteria and were divided into sensory loss and control (sensory normal) groups; the sensory loss participants were defined by the inability to detect a 5.07 Semmes–Weinstein monofilament on any of the plantar positions (Feng et al., 2009). Both groups experienced a 16-week TC intervention; data from participants with less than 70% attendance rate were excluded (Fuzhong et al., 2018). Fourteen participants from the sensory loss group and 17 participants from the control group were left after the intervention. All participants gave a written informed consent before participating in the study. Human participation was approved by the Institutional Review Boards at Shandong Sport University (19,003) and was in accordance with the Declaration of Helsinki. A priori power analysis (G*Power Version 3.1) indicated that a minimum of 11 participants are needed to obtain the alpha level of 0.05 and the beta level of 0.80 based on a previous report, which compared the ankle plantar flexion proprioception before and after a 24-week TC intervention (Chang et al., 2016).

TC intervention

TC intervention lasted for 16 weeks, and was organized and monitored by a qualified TC instructor. In the first 8 weeks, the participants were instructed to practice TC for four sessions per week, 1 h per session. Each session included a 10 min warm-up, 20 min to learn new movements, 20 min to review the new movements, and a 10 min cool-down. After 8 weeks, participants practised TC for four sessions per week, 1 h per session. Each session included a 5 min warm-up, 50 min intervention, and a 5 min cool-down. The instructor recorded the attendance of the participants (Zhang et al., 2015).

Protocol

Data were collected before and after TC intervention at weeks 0 and 17, respectively. At week 0, the participants who came into the Biomechanics Laboratory were given an overview of the research and signed an informed consent form. The supplement information included the MMSE and a participant Medical History sheet. It was used to determine whether the participants would be excluded from the study. At weeks 0 and 17, the cutaneous sensitivity and proprioception tests were performed. The skin temperature at the right gastrocnemius was measured during the test (IRT0421, Infrared Thermometer, Kintrex, TX, USA) (Figure 1).

Cutaneous sensitivity test

Cutaneous sensitivity test was performed by having the participants lay down with their backs against the treatment table and was assessed with a set of Semmes–Weinstein monofilaments (North Coast Medical, Inc., Morgan Hill, CA, USA) (Perry, 2006). Six monofilaments with different sizes were used in this study: 2.83 (0.07 g), 3.61 (0.4 g), 4.31 (2 g), 4.56 (4 g), 5.07 (10 g), and 6.65 (300 g). Filament size = $\log_{10}$ (10 * force in milligrams). They

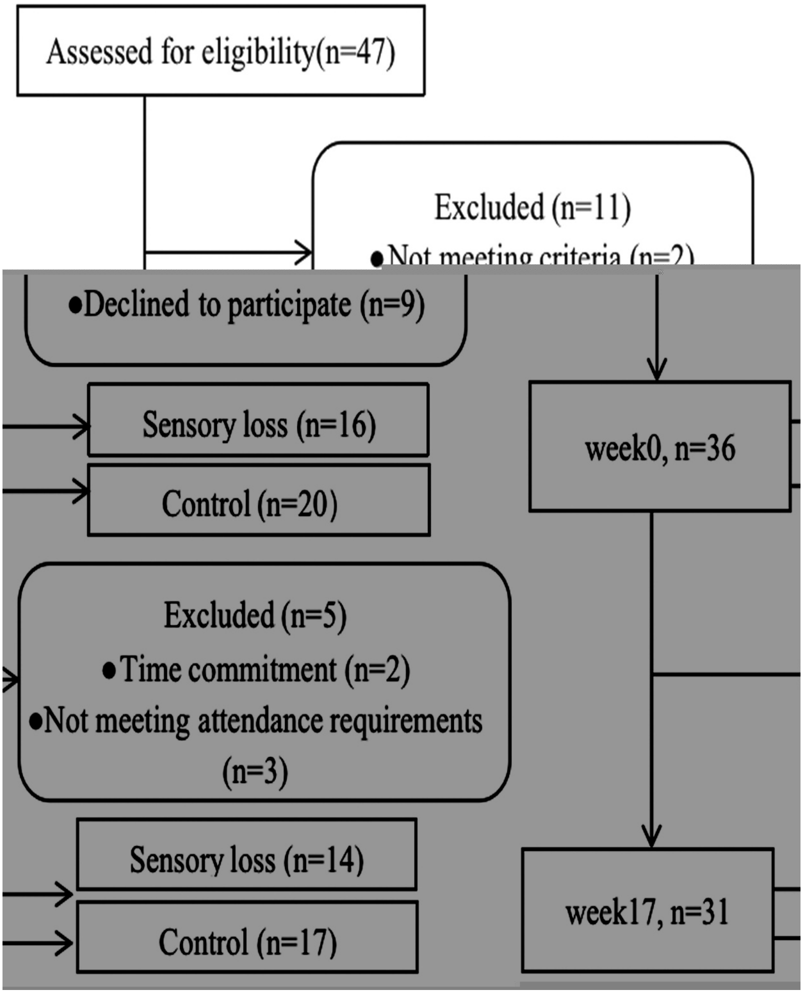

Figure 1. Participant flow chart from week 0 to week 17. Final analysis included data from 31 participants. Forty-seven participants were assessed for eligibility; 36 qualified were divided into the sensory loss or control group. At week 17, five participants were excluded because of time commitment, receiving other intervention, or with an attendance rate below 70%. After the 16-week Tai Chi intervention, 17 participants remained in the control group, and 14 remained in the sensory loss group.

were applied to the skin (bent 90°) on the right hallux, first/fifth metatarsals, arch and heel in a random order. Randomized null-stimuli were added to ensure that the participants could not anticipate the application of the filaments. The sensory threshold was determined by initially presenting supra-threshold filaments and then applying thinner filaments until the subjects could no longer detect them. Participants were asked to give a verbal response about the localization of the area tested when they perceived the stimulation. The cutaneous sensitivity threshold was determined by the thinnest monofilament (Feng et al., 2009). The lower the sensation threshold, the better the cutaneous sensitivity.

Proprioception test

Proprioception during right-knee flexion/extension and ankle dorsi/plantar flexion angle was assessed using a proprioception test device, which showed good test–retest reliability (ICC value, 0.737–0.935) (Sun et al., 2015). The platform was driven by two electric motors at an angular velocity of 0.4°/s. The movement of the platform could be stopped at any time by a hand switch. The angular displacement of the platform was measured by an electronic goniometer. During data collection, each participant was seated in an adjustable chair with the dominant foot placed on the platform so that the frontal and sagittal axes of the device were approximately parallel to the plantar/dorsal axis of the ankle joint. The knee joints were flexed at 90°, and the lower leg was perpendicular to the surface of the platform when the platform was in a horizontal position. Participants closed their eyes and wore headphones with music playing to eliminate any visual or auditory stimuli from the testing environment. Participants were instructed to concentrate on their feet and knees and to press hand switches to stop the movement of the platform when they could sense motion followed by an identification of the rotation direction. The motor was operated to rotate the knee to flexion and extension and the ankle to plantar flexion and dorsal flexion in a random order with a random time interval ranging from 2 s to 10 s after an indication to start a trial. Each trial was started with the platform in the horizontal position. At least five trials were performed in each direction. The minimal three angles sensed in each direction were used for data analysis. The lower the angle, the better the proprioception.

Data analysis

The normality of all outcome variables was tested using the Shapiro–Wilk test. The main effect of time (intervention) and time–group interaction was confirmed with a two-way ANOVA with repeated measures (normally distributed data) or a Scheirer–Ray–Hare test (non-normally distributed data) while controlling for the covariates, gender, age, height, and weight. If significant interactions were detected, a post hoc paired sample *t* test (normally distributed data) or Wilcoxon Signed Rank test (non-normally distributed data) was performed to compare pre- and post-values for the two groups, respectively. All analyses were conducted in SAS 9.4, and the significant level was set at 0.05.

Results

Shapiro–Wilk tests showed that the cutaneous sensitivity data were non-normally distributed, and the proprioception data were normally distributed; hence, Scheirer–Ray–Hare tests and two-way ANOVA tests with repeated measures were applied accordingly.

Forty-seven participants were assessed for eligibility; 36 were qualified and divided into the sensory loss or control group. At week 17, five participants were excluded because of time commitment, receiving other intervention or with an attendance rate below 70%. After the 16-week TC intervention, 17 participants (10 females, age: 67.30 ± 2.64 years, height: 164.18 ± 1.13 cm and body mass: 64.70 ± 9.15 kg) remained in the control group, and 14 participants (five females, age: 73.86 ± 8.99 years, height:

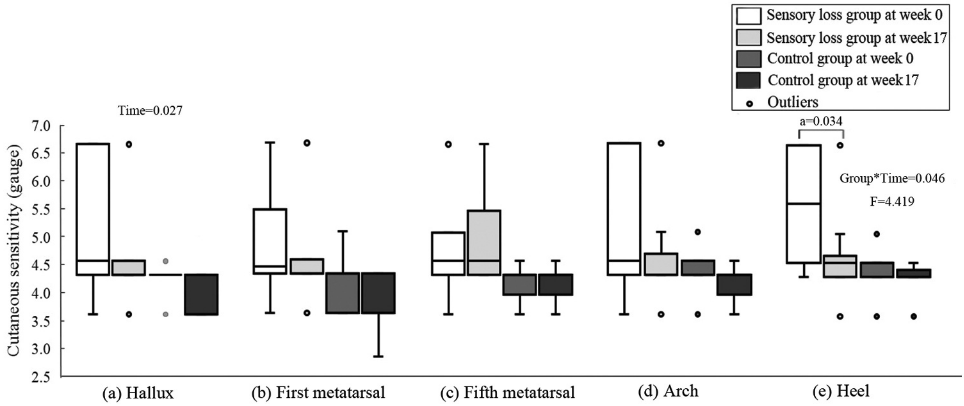

Figure 2. Box plots for site-specific plantar sensitivity threshold with and without sensory loss before and after a 16-week Tai Chi intervention. [a] Significant difference between week 0 and week 17 in the sensory loss group

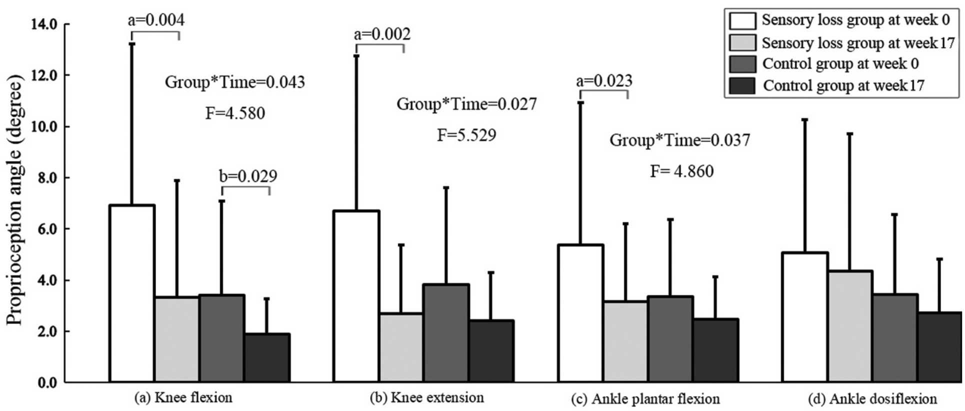

Figure 3. Proprioception among the older adults with and without sensory loss before and after a 16-week Tai Chi intervention. [a] Significant difference between week 0 and week 17 in the sensory loss group [b] Significant difference between week 0 and week 17 in the control group

160.2 ± 7.61 cm, and body mass: 63.23 ± 6.41 kg) remained in the sensory loss group (Figure 2).

The site-specific cutaneous sensitivity threshold among the older adults with and without sensory loss was detected at weeks 0 and 17. Significant interaction was detected between the two groups on the heel (p = 0.046, F = 4.419). In the sensory loss group, the cutaneous sensitivity threshold significantly decreased at week 17 on the heel (p = 0.034), compared with that at week 0. The main time (intervention) effect was detected on the hallux (p = 0.027), the cutaneous sensitivity threshold decreased at week 17 on hallux in sensory loss and control groups, compared with that at week 0 (Figure 2).

The proprioception threshold among the older adults with and without sensory loss was detected at weeks 0 and 17. Significant interactions were found during knee flexion (p = 0.043, F = 4.580), extension ($p = 0.027$, $F = 5.529$) and ankle plantar flexion ($p = 0.037$, *F* = 4.860). In the sensory loss group, the proprioception threshold during knee flexion (p = 0.004), knee extension (p = 0.002), and ankle plantar flexion (*p* = 0.023) decreased at week 17, whereas in the control group, the proprioception angle during knee flexion (*p* = 0.029) decreased at week 17, compared with that at week 0 (Figure 3).

Discussion

This study was the first to investigate the effects of a 16-week TC intervention on site-specific cutaneous sensitivity and multi-joint proprioception among the older adults with and without sensory loss. TC intervention significantly increased cutaneous sensitivity and proprioception. TC intervention improved cutaneous sensitivity at more sites and proprioception of more joints among the older adults with sensory loss.

Cutaneous sensitivity

The outcomes of this study supported our first hypothesis that a 16-week TC intervention could improve cutaneous sensitivity at the hallux and heel. The range of our results was consistent with previous studies (Unver & Akbas, 2018), in which TC intervention significantly improved cutaneous sensitivity among the older adults with PN by altering ring the plasticity of the sensory-motor system to increase the somatosensory information from the plantar mechanoreceptors (Li & Manor, 2010). This enhancement of cutaneous sensitivity might be attributed to an expanded representation of the primary somatosensory cortex (Liranisilva et al., 2017). Another study suggested the presence of underlying physiological changes, primarily in the form of increased plantar sensory function (Wang et al., 2001). This improvement was attributed to the increase in peripheral blood microcirculation and indicated that TC exercises could enhance endothelial and peripheral circulations and plasma nitric oxide levels (Wang et al., 2001). This finding might indicate that TC could augment endothelium-dependent dilation of skin vasculature by increasing acetylcholine-induced cutaneous perfusion (Wang et al., 2001). In this study, cutaneous sensitivity increased after TC intervention, indicating that TC is an effective intervention for improving cutaneous sensitivity among the older adults.

The significant interaction between the two groups in the heel supported our first hypothesis that TC improved cutaneous sensitivity at more sites among the older adults with sensory loss. PN, including sensory loss, caused a range of symptoms on the basis of the distribution and types of nerve fibres involved. In mammals, discriminative light touch perception was mediated by primary sensory neurons, namely, low-threshold mechanoreceptors (Fleming & Luo, 2013; Li et al., 2019). Cell bodies are located in the dorsal root ganglia and trigeminal ganglia, which extend a central projection innervating the spinal cord and brain stem and peripheral projection innervating the specialized mechanosensory end organs (Fleming & Luo, 2013). Among the older adults with sensory loss, peripheral nerves may have undergone morphological changes (Crone & Krarup, 2013). Major pathological changes in peripheral nerve fibres include axonal loss and demyelination. In most cases of demyelinating neuropathy, considerable axonal loss is found (Crone & Krarup, 2013). Therefore, the effects of TC intervention may be enhanced among the older adults with sensory loss. It is recommended the older adults begin TC exercises as early as possible.

Proprioception

The outcomes of this study supported our second hypothesis that a 16-week TC intervention could improve proprioception among the older adults with and without sensory loss. Many interventions, such as sensorimotor training (Ahmad et al., 2019) and exergaming (Sadeghi et al., 2017), could enhance proprioception among the older adults. TC intervention was more beneficial in enhancing proprioception than some normal exercises, such as brisk walking (Zhang et al., 2015). In practising TC, most of the movements require holding the half-squat posture for a relatively long time. This posture indicates that the muscles around the knee joint are being exercised, thereby improving knee stability and proprioception (Chang et al., 2016). The ankle joint is the closest joint to the ground and carries the most weight throughout the body. When practising TC, posture and step changes require ankle joint movements, such as raising or lowering of the toes and turning the toes inward or outward. This study showed the improvement of ankle proprioception. The outcomes of this study were in accordance with a systematic review of 11 papers conducted in 2018, in which a moderate-to-strong effectiveness of TC intervention on improving lower limb proprioception was proven among older adults (Zou et al., 2019). Significant interactions between the two groups during knee flexion and extension indicate that TC improves more joint proprioception among the older adults with sensory loss, compared with the control group. It can be explained that before the TC intervention, the proprioception of the elderly with sensory loss was worse than that of the control group, and it was easier to improve the reduced proprioception..

Sensory nerves do not work independently of each other, and proprioceptive and cutaneous afferents connect interneurons together in the posterior root of the dorsal root (Li et al., 2019). Interneurons connect α-motor neuron with cutaneous sensitivity and proprioception. Increased cutaneous sensitivity could enhance proprioception (Mildren et al., 2017).

Limitation

This work had several limitations. First, except for the cutaneous sensitivity tested in this study, the cutaneous vibration sensation was another critical sensory source for balance control (Perry, 2006). This study failed to demonstrate the effect of TC on the cutaneous vibration sensation. Second, TC intervention lasted for 16 weeks, from August to December 2019. Thus, the outcomes could be influenced by seasonal temperature changes. Third, TC is a multi-joint exercise, and in this study, proprioception at two different joints was measured separately. Proprioception improvements at both knee and ankle joints, along with the improved plantar sensitivity, would work together to improve the multi-joint interaction during human movement, especially when postural control is required. Future study needs to explore the influence of multiple sensory input changes on multi-joint interactions during human locomotion and postural stability.

Conclusion

TC intervention could improve cutaneous sensitivity and proprioception among the older adults with and without sensory loss; TC intervention improved cutaneous sensitivity at more sites and proprioception in more joints among the older adults with sensory loss.

Acknowledgements

This work was supported by the China Shandong Education Department under Grant Movement Science Research Innovation Team (2019-183); Ministry of Science and Technology of China under Grant the National Key R&D Program of China (2018YFC2000600). The authors would like to thank Xiu Hu, Fang Liu, Hengshuo Zhang, Xiao Gao, and Huifen Zheng, graduate students at Shandong Sport University, for participating in the experiment and data acquisition for this work.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Shandong Provincial Youth Talent Induction Team [2019-183]; National Key R&D Program of China [2018YFC2000600].

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