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# Long Term Tai Chi Exercise Improves Physical Performance Among People with Peripheral Neuropathy

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Abstract: This study examined the effects of a 24-week Tai Chi intervention on physical function in individuals with peripheral neuropathy. Twenty-five women and men with peripheral neuropathy were recruited. Plantar pressure detection threshold was assessed with a 5.07 gauge monofilament. Functional gait was assessed by the 6-min walk and timed up-and-go tests. Isokinetic leg strength and standing balance was also assessed. Twenty-four consecutive weeks of modified, group-based Tai Chi practice was completed, with testing repeated every six weeks throughout. No adverse events were observed and attendance was $17 \pm 4$ sessions per 6 weeks. After 6 weeks of Tai Chi, participants increased 6-min walk ($P < 0.0001$), timed up-and-go ($P < 0.0001$), and leg strength ($P < 0.01$) performance. Continued improvement was observed in the timed up-and-go. Plantar sensation improved ($P = 0.003$) following the Tai Chi intervention. Group-based Tai Chi is a safe, plausible, and effective intervention for those with PN.

*Keywords*: Tai Chi; Peripheral Neuropathy; Cutaneous Sensation; Mobility.

## Introduction

The 108th US Congress (2005) estimated that at least 20 million US citizens suffer from chronic diffuse neuropathy, or peripheral neuropathy (PN). PN is common particularly in older cohorts and in those with Diabetes Mellitus (Franklin *et al.*, 1990; Martyn and

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Hughes, 1997). Based on existing epidemiological data (Franklin *et al.*, 1990; Harris *et al.*, 1998), it has been estimated to affect over 20% of all individuals age from 60 to 74 years (Richardson, 2002).

PN is marked primarily by progressive deterioration of distal sensory nerves (Boulton *et al.*, 2004). This deterioration gives rise to both positive (e.g., hypersensitivity to pain) and negative systems (e.g., numbness) (Apfel *et al.*, 2001), and leads to reduced sensitivity across all sensory modalities with time (Boulton *et al.*, 2004). Plantar pressure and vibration detection thresholds are particularly disrupted. Dingwell and Cavanagh (2001) reported that the minimum detectable buckling force of diagnostic monofilaments, which apply a calibrated pressure to the plantar aspect of the foot, was 35 times greater at the heel, and over 400 times greater at the hallux, in PN patients as compared to the age-matched controls.

Loss of sensation associated with PN has been linked to movement disturbances during weight-bearing situations. Those with PN are at increased risk of suffering both reduced mobility (van Schie, 2008) and falls (Richardson and Ashton-Miller, 1996). Individuals with PN walk 20–30% slower than age-matched healthy controls (DeMott *et al.*, 2007) and have difficulty adapting their walking patterns to irregular surfaces and relatively fast walking speeds (Manor *et al.*, 2008b; Menz *et al.*, 2004). Standing balance, assessed by static posturography, has also been reported to be severely affected. Compared to healthy controls, Yamamoto *et al.* (2001) observed that individuals with diabetic PN demonstrated 245% and 159% increases in average area and velocity respectively of center of pressure movement during eyes-closed conditions.

Despite these well-characterized movement disturbances, relatively little research has examined the effectiveness of exercise intervention within this population. Preliminary research by Richardson *et al.* (2001) has demonstrated that a three week exercise program focusing on strengthening "balance specific" lower-extremity musculature improved functional reach, uni-pedal and tandem stance times in this population. However, a more recent review article concluded that inadequate evidence was available to evaluate the effectiveness of exercise programs for this population (White *et al.*, 2004).

Tai Chi is a mind-body martial arts form that has recently gained popularity within rehabilitative settings. It is an "exercise based on slow intentional movements, often coordinated with breathing and mental imagery, which aims to strengthen and relax the physical body and mind" (Wayne and Kaptchuk, 2008). Tai Chi practice, which may be tailored to specific needs of a population, has been demonstrated to safely improve balance and gait in the elderly (Lin *et al.*, 2006; Wolf *et al.*, 1997a), frail (Wolf *et al.*, 1996), and diseased populations (Hackney and Earhart, 2008). Tai Chi's effectiveness in even high-risk populations makes it a promising candidate for interventions aimed at alleviating movement disturbances associated with PN.

The purpose of the present study was to examine the capacity of modified, group-based Tai Chi practice to safely and effectively improve cutaneous sensation, strength, balance, and physical function within those with clinically diagnosed PN.

## Methods

### *Participants*

Twenty five individuals with PN gave informed consent. The project was approved by the local Intramural Review Board. The presence of PN was first determined by a neurologist. As diagnostic criteria vary across physicians (Boulton *et al.*, 2004), the presence of PN was experimentally confirmed by plantar pressure detection threshold (PPDT) testing. This diagnostic test has low incidence of false-positive results when compared to gold-standard electro-diagnostics (Kamei *et al.*, 2005), thus making it a conservative test for the presence of PN.

PPDT testing was conducted with the participant seated with eyes-closed and right leg supported. The 5.07 gauge Semmes-Weinstein monofilament (North Coast Medical, Inc., Morgan Hill, CA, USA) was employed using standard procedures. Testing sites included the heel, mid-sole, bases of first/fifth metatarsals and hallux (Nurse and Nigg, 2001). Each site was tested three times in random order. Individuals were instructed to say "Yes" if pressure was felt. Intact sensation at each site was defined by two or more correct (i.e., yes) responses and was given a score of "1." Abnormal sensation, defined by two or more incorrect responses, was given a score of "0." Assigned scores for each site were added to produce a score from 0–5.

Inclusion into the study was thus contingent upon (1) physician-diagnosed PN, (2) plantar pressure detection threshold score $\leq 3$. Potential participants were excluded if they presented with foot ulceration, any other movement disorder that may affect physical performance, or any uncontrolled cardiovascular, respiratory, or metabolic disorder.

### *Functional Assessment*

In addition to PPDT testing, participants completed a battery of tests of functional gait, standing balance, and leg strength. All tests were previously observed to be reliable within this population (Manor *et al.*, 2008a). Functional gait was measured by the 6-min walk (6 MW) and Timed Up-and-Go (TUG) tests. The 6 MW was conducted with two cones placed on opposite ends of a 30 m hallway. Participant instructions were to walk around the cones and cover as much distance as possible in six minutes (Brooks *et al.*, 2003). The distance walked to the nearest meter was recorded. The TUG was administered with an armed chair placed in the middle of indoor hallway. A cone was placed 3 m in front of the chair. The participant began seated with their back against the chair. Instructions were to stand up using the arm rests if needed, walk safely around the cone and back to the chair, and sit back in the chair as fast as possible (Podsiadlo and Richardson, 1991). The average time needed to complete each of two trials was used for analysis.

Knee extensor (KEPT) and flexor peak torque (KFPT) were measured at 60 deg/sec with a Biodex dynamometer (Biodex Medical, Shirley, NY, USA). Warm-up consisted of five reciprocal knee extension/flexion movements. Following rest, five maximal trials were completed with 10 sec rest between trials. Verbal encouragement was provided to facilitate

maximal efforts. Of the five extension/flexion movements, the greatest three peak torques were recorded and averaged.

Standing balance was assessed using an AccuSway ®; force platform and SWAYWIN 95 version 2.1 software (Advanced Mechanical Technologies, Inc., Watertown, MA, USA). Participants completed three 30-sec trials with normal stance (i.e. heels five cm apart, feet abducted laterally 10 degrees), arms by their side, and eyes closed. For each trial, the average velocity (VEL) of the body center of pressure, and the area of a bivariate confidence ellipse inclosing 95% of the center of pressure trajectory (A95) (Prieto *et al.*, 1996) were calculated.

Following initial testing (Week 0), participants were enrolled in an on-going community outreach program consisting modified Tai Chi practice (described below). PPDT and functional testing were repeated every six weeks for 24 weeks (Weeks 6, 12, 18 and 24). There was no control group assigned in this study due to the well documented deterioration of physical function among this group if left untreated. For more detailed information please see van Schie (2008) and Richardson and Ashton-Miller (1996).

### *Tai Chi Exercise*

Tai Chi practice included three, one-hour, instructor-led group sessions per week. Approximately 15 min of warm-up exercises were completed. These exercises emphasized rhythmical movements (e.g., arm swings, trunk rotations, etc.), mediation, and the regulation of breathing. Participants were progressed into a modified eight-form Yong Style of Tai Chi similar to Wolf *et al.* (1997b). Each form consisted of a specific sequence of coordinated whole-body movements and controlled breathing. All participants began Tai Chi practice from a seated position and were progressed into standing with and without the assistance of a chair. Progression was individualized and was based upon the discretion of the Tai Chi instructor.

### *Data Analysis*

The effects of Tai Chi exercise on physical function, standing balance, leg strength and PPDT were analyzed with one-way, repeated-measure ANOVAs with testing session (Weeks 0, 6, 12, 18 and 24) included as the within-subject factor. Trend and Tukey's *post-hoc* analyses were used whenever needed. Pearson product correlation analysis was performed between all functional test variables collected at all five testing sessions. To test how concerned physical tests variables (KEPT, KFPT, AREA, VEL, PPDT) contributed to field test (6 MW and TUG) performance, stepwise linear regressions were performed. Data collected from all five sessions were included in the regression analysis. Significance level was set at alpha $= 0.05$ for all analyses.

## Results

Twenty five participants (8 men, 17 women, age $= 71 \pm 12$ years old, body mass $= 76 \pm 18$ kg, height $= 168 \pm 9$ cm) completed all five testing sessions. Participants completed an

average of $17 \pm 4$ Tai Chi exercise sessions between each testing session. No adverse events were observed throughout all experimental procedures.

The effects of long-term Tai Chi practice on functional gait are presented in Figs. 1 and 2. Participants demonstrated marked improvement in 6 MW distance ($F_{4,96} = 12.93$, $P < 0.0001$) and TUG time ($F_{4,96} = 16.19$, $P < 0.0001$). For the 6 MW, *post-hoc* analysis revealed a significant linear trend ($F_{1,96} = 10.95$, $P < 0.0001$) across testing sessions. *Post-hoc* analysis revealed that 6 MW distance increased from Week 0 (416 m) to Week 6 (442 m), with no further significant continued at Week 12 (451 m), Week 18 (462 m), or Week 24 (461 m). TUG improvement followed both linear ($F_{1,96} = 13.03$, $P < 0.0001$) and quadratic ($F_{1,96} = 2.98$, $P = 0.023$) trends. *Post-hoc* analysis revealed significant improvements at Week 6 (9.4 sec) and Week 12 (8.9 sec) as compared to Week 0

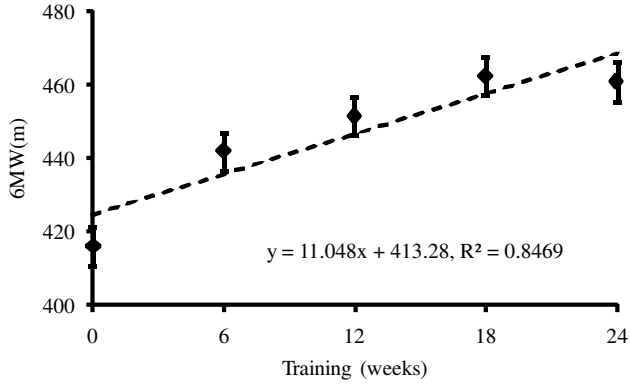


Figure 1. Six minute walk (6 MW) distance plotted over 24 weeks of Tai Chi training at 6 week intervals, along with the linear regression equation and R-square value. The whiskers represent the standard deviation of the mean. See relevant text for more details.

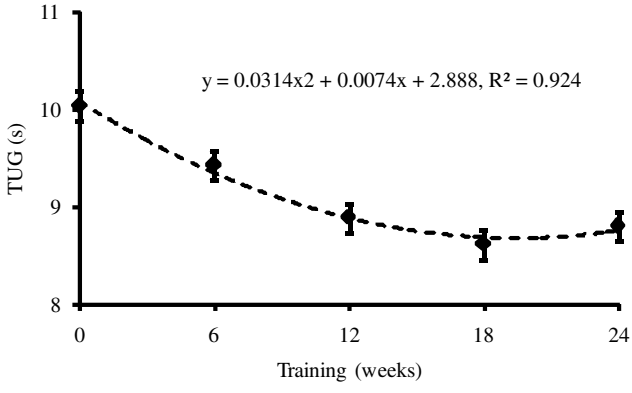


Figure 2. Timed up-and-go (TUG) duration (sec) plotted over 24 weeks of Tai Chi training at 6 week intervals, along with the quadratic regression equation and R-square value. The whiskers represent the standard deviation of the mean. See relevant text for more details.

(10.0 sec). Further significant improvements were also observed at Week 18 (8.6 sec) and Week 24 (8.8 sec) as compared to Week 6.

Eyes-closed standing balance, as assessed by the AREA and VEL, presented no observable change throughout the study period.

The effects of Tai Chi practice on leg strength are presented in Figs. 3 and 4. KEPT was improved significantly ($F_{4,96} = 7.43$, $P < 0.0001$), following a linear trend ($F_{1,96} = 4.67$, $P = 0.0017$). KFPT also improved significantly ($F_{4,96} = 6.58$, $P = 0.0001$), and likewise followed a linear trend ($F_{1,96} = 3.91$, $P = 0.0056$). *Post-hoc* analysis revealed that KEPT and KFPT increased from Week 0 (85 & 42 N) to Week 6 (94 & 47 N). No further significant improvements were observed at Week 12 (93 & 46 N), Week 18 (95 & 48 N), or Week 24 (95 & 48 N).

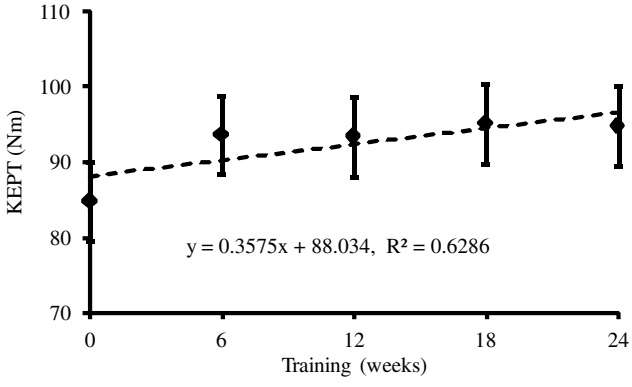


Figure 3. Peak knee joint extension torque (Nm) at 60°/s (KEPT) plotted over 24 weeks of Tai Chi training at 6 week intervals, along with the linear regression equation and R-square value. The whiskers represent the standard deviation of the mean. See relevant text for more details.

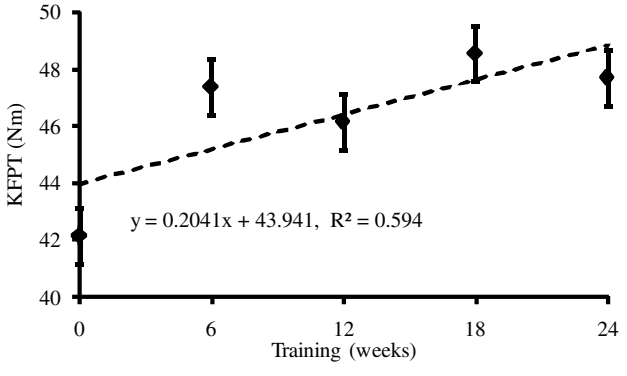


Figure 4. Peak knee joint flexion torque (Nm) at 60°/s (KFPT) plotted over 24 weeks of Tai Chi training at 6 week intervals, along with the linear regression equation and R-square value. The whiskers represent the standard deviation of the mean. See relevant text for more details.

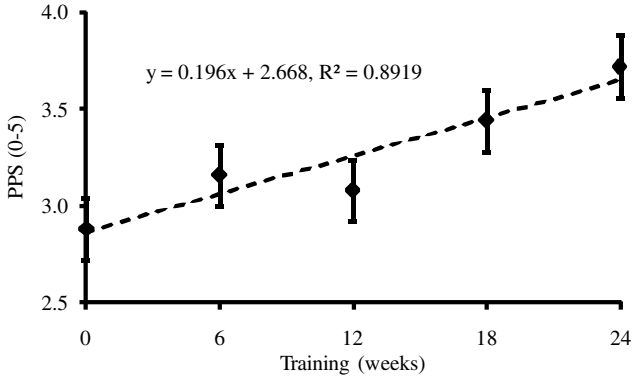


Figure 5. Results of the five-point plantar pressure detection threshold (PPDT) test plotted over 24 weeks of Tai Chi training at 6 week intervals, along with the linear regression equation and R-square value. The whiskers represent the standard deviation of the mean. See relevant text for more details.

Surprisingly to us, PPDT was improved significantly ($F_{4,96} = 4.22$, $P = 0.0034$) over the 24 week study (see Fig. 5 for details). This improvement was followed a linear trend ($F_{1,96} = 3.76$, $P = 0.0069$), with *post-hoc* analysis revealing that Week 24 PPDT (2.88) was greater than that of Week 0 (3.72).

Although eyes-closed standing balance (i.e., AREA and VEL) did not improve over the 24 week study, each was significantly correlated to PPDT (PPDT vs. AREA, $r = -0.34$, $P <= 0.001$; PPDT vs. VEL, $r = -0.50$, $P < 0.001$). AREA in turn was highly correlated with 6 MW ($r = -0.2226$, $P = 0.0126$) and TUG ($r = 0.2074$, $P = 0.0203$). The correlations between VEL and these two variables were not significant.

As functional gait (6 MW and TUG) was significantly improved with Tai Chi practice, regression analysis was completed to determine if specific tested variables (PPDT, AREA, VEL, KEPT, KFPT) could be used to predict these improvements. Both 6 MW and TUG were highly predicted by AREA and KEPT while other variables (VEL, KFPT and PPDT) had no significant contribution to the regressions. The regression equations for 6 MW and TUG were:

$$6\text{MW} = 403.83 - 2.52*\text{AREA} + 0.70*\text{KEPT}, R^2 = 0.1940;$$
$$\text{TUG} = 10.274 + 0.051*\text{AREA} - 0.017*\text{KEPT}, R^2 = 0.2188.$$

## Discussion

The current study investigated the safety and effectiveness of Tai Chi practice for those suffering from PN. The modified, group-based Tai Chi classes were very well attended by study participants. Average attendance for each of the four consecutive six-week sessions was 17 out of a possible 18 classes. In the entire 24 week study period, the 25 participants did not report a single adverse event or injury. Taken together, these results

strongly support group-based Tai Chi practice is a plausible exercise mode within this population.

The PN participants attending the Tai Chi intervention demonstrated improved functional gait, strength, and even plantar sensation as assessed by standard monofilament testing. The majority of improvements in functional gait and leg strength were observed after only six weeks of Tai Chi practice. For the remaining 18 weeks, participants either continued to improve (TUG test) or maintained performance (6 MW, KEPT, KFPT) at levels significantly greater than the baseline. The improvements observed after only six weeks of intervention were expected as Richardson *et al.* (2001) reported functional balance improvements in those with PN after only three weeks of training. Furthermore, Tai Chi has been proven as an effective stimulus for improving physical function within this timeframe in other populations (Shen *et al.*, 2008).

Improvements in functional gait and leg strength were not as consistent and or pronounced after the initial six weeks of training. However, PN is both a chronic and progressive condition. Deterioration of protective cutaneous sensation, a manifestation of increasing involvement of the peripheral nervous system, is closely associated with the severity of associated movement disorder. For example, Menz *et al.* (2004) reported both plantar vibration and tactile sensory thresholds were significantly and negatively associated with walking speed, especially over irregular surfaces, within this population. Therefore, the observation that study participants maintained their initial improvements in functional gait and leg strength lends further evidence in favor of Tai Chi as an effective means of intervention within this population.

It is generally believed that there is no cure for PN (Boulton *et al.*, 2004). Few reports have demonstrated improved cutaneous sensation following non-surgical intervention (Yu *et al.,* 2008; Harkless *et al.,* 2006). In the current study, plantar pressure detection thresholds were tested using a reliable method that assessed the ability to detect the 5.07 gauge Semmes-Weinstein monofilament at five weight-bearing plantar sites (Manor *et al.*, 2008a). The number of detected sites was significantly greater at 24 Weeks compared to the baseline. This important observation is supported by Richerson and Rosendale (2007), who similarly demonstrated that six months of modified Tai Chi practice in those with diabetic PN significantly improved vibration detection thresholds on the plantar surfaces of the feet.

Individuals completing the Tai Chi practice intervention did not demonstrate significant change in eyes-closed standing balance. Wolf *et al.* (1997a) reported that in previously inactive, healthy older men and women, 15 weeks of Tai Chi practice reduced fear of falling but did *not* improve standing balance as defined by relative reduction in postural sway magnitude during standing. In fact, the participants in that study demonstrated *increased* postural sway magnitude in eyes-open sway at post-intervention assessment. The authors speculated that the unique characteristics of Tai Chi practice, namely, progressively increasing body movements over progressively decreasing bases of support, may have been incorporated into the neuromuscular control of standing balance in these practitioners. This speculation is in support of the dynamical systems theory that variability in biological systems (i.e., postural sway) may be advantageous because it

allows for the adaptation to environmental stresses or physical perturbations (Kelso, 1995). In this light, the observed lack of change in postural sway does not necessarily suggest lack of dynamic balance improvement. Insight into this issue would be gained from future research examining the effects of Tai Chi on standing balance control as measured by the responsiveness to stresses such as (cognitive) dual tasks and/or support surface perturbations.

The relatively consistent improvement in functional gait over the 24 week Tai Chi intervention prompted a secondary investigation into potential underlying factors associated with 6 MW and TUG performance. Measures of leg strength, standing balance, and plantar sensation were included in regression analyses. Of the included measures, only KEPT and AREA were related to performance both the 6 MW and TUG tests. Individuals with greater KEPT and smaller AREA tended to perform better in each test. Certainly, measurement and inclusion of additional variables such as fear of falling, bodily pain, ankle joint power, etc., would have strengthened regression models. However, the results are encouraging as each variable, and in particular that of KEPT, appear to be largely modifiable within this population.

It is unknown if the observed improvements in functional gait and plantar pressure sensation resulted from chronic exercise in general, or from the specific characteristics of Tai Chi practice. This traditional form of Chinese medicine combines bodily movements with meditation and controlled breathing. It is therefore distinctly different from walking, cycling, or other forms of aerobic exercise. Physically, it is relatively non-strenuous and low impact, and is characterized by postural alignment, weight shifting, and relaxed circular movements. It also stresses coordination and synchronization between these movements and breathing patterns. Mentally, it emphasizes focused attention on movement form, and encourages practitioners to perceive how the body "feels" during practice. This holistic, mind-body approach is believed to critically underlie Tai Chi's effectiveness as a rehabilitation intervention [please see Yuan *et al.* (2006) and Xutian *et al.* (2009) for a more detailed discussion regarding Tai Chi as part of traditional Chinese medicine]. Future research should therefore be designed to directly test the effectiveness of Tai Chi as compared to other interventions such as strength or aerobic training.

In conclusion, the 24 week Tai Chi intervention program was both safe and effective for individuals with PN. The effectiveness of this intervention was highlighted by significant functional gait and leg strength gains in as little as six weeks, with no deterioration thereafter. The observed improvement in plantar pressure sensation by the end of the 24 week program is an exciting result that warrants additional investigation with more sophisticated tests of cutaneous sensation, lower-extremity nerve conduction velocity, and peripheral circulation. Together, the observations of the current study have demonstrated that Tai Chi is a plausible intervention with several beneficial effects of the physical well-being of individuals with PN.

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