Published in final edited form as:

Parkinsonism Relat Disord. 2013 November ; 19(11): . doi:10.1016/j.parkreldis.2013.06.007.

The Effect of Tai Chi Exercise on Gait Initiation and Gait Performance in Persons with Parkinson's Disease

Shinichi Amano, PhD.¹, Joe R. Nocera, PhD.^{2,4}, Srikant Vallabhajosula, PhD.³, Jorge L. Juncos, MD.⁴, Robert J. Gregor, PhD.^{5,6}, Dwight E. Waddell, PhD.⁷, Steven L. Wolf, PhD, PT, FAPTA.^{2,8}, and Chris J. Hass, PhD.¹

¹Department of Applied Physiology & Kinesiology, University of Florida, Gainesville, FL, USA

²VA Rehabilitation R&D Center of Excellence, Atlanta VAMC, Atlanta, GA, USA

³Department of Physical Therapy Education, Elon University, NC, USA

⁴Department of Neurology, Emory University School of Medicine, Atlanta, GA, USA

⁵School of Applied Physiology, Center for Human Movement Studies, Georgia Institute of Technology, Atlanta, GA, USA

⁶Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA, USA

⁷Departments of Electrical Engineering, and Health, Exercise Science and Recreation Management, University of Mississippi, MS, USA

⁸Departments of Rehabilitation Medicine, Medicine and Cell Biology, Emory University School of Medicine, Atlanta, GA, USA

Abstract

Gait dysfunction and postural instability are two debilitating symptoms in persons with Parkinson's disease (PD). Tai Chi exercise has recently gained attention as an attractive intervention for persons with PD because of its known potential to reduce falls and improve postural control, walking abilities, and safety at a low cost. The purpose of this report is to investigate the effect of Tai Chi exercise on dynamic postural control during gait initiation and gait performance in persons with idiopathic PD, and to determine whether these benefits could be replicated in two different environments, as complementary projects. In these two separate projects, a total of 45 participants with PD were randomly assigned to either a Tai Chi group or a control group. The Tai Chi groups in both projects completed a 16-week Tai Chi exercise session, while the control groups consisted of either a placebo (i.e., Qi-Gong) or non-exercise group. Tai Chi did not significantly improve Unified Parkinson's Disease Rating Scale Part III score, selected gait initiation parameters or gait performance in either project. Combined results from both projects suggest that 16 weeks of class-based Tai Chi were ineffective in improving either gait initiation, gait performance, or reducing parkinsonian disability in this subset of persons with PD. Thus the use of short-term Tai Chi exercise should require further study before being considered a valuable therapeutic intervention for these domains in PD.

© 2013 Elsevier Ltd. All rights reserved.

Corresponding author: Chris J. Hass, PhD., University of Florida, Department of Applied Physiology and Kinesiology, P.O. Box 118205, Rm 100 Florida Gym, Gainesville, FL 32611, Tel: (352) 294-1716, cjhass@hnp.ufl.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Keywords

Balance; Gait; Parkinson's Disease; Tai Chi; Exercise; Rehabilitation

Introduction

Gait dysfunction and postural instability are two debilitating symptoms in persons with Parkinson's disease (PD) [1]. These motor impairments lead not only to decreased mobility, but an increased incidence of falls. Approximately 70% of persons with PD fall during the course of the disease, often resulting in serious consequences. [2–4]. Lower extremity impairments contributing to gait dysfunction and postural instability also have powerful effects on self-reported motor and psychological quality of life [5, 6]. Thus, improvement in locomotor abilities is frequently cited as one of the more relevant outcomes necessary to deem antiparkinson treatment a success [7].

Exercise training has been recommended for persons with PD because of the established relationship between exercise and improved cardiovascular and physical function as well as overall health and well-being [8, 9]. Given the known benefits in other populations as well as safety and low cost, Tai Chi (TC) exercise has been widely promoted as appropriate for older adults. TC has been shown to provide general health benefits (e.g., flexibility, strength, and cardiovascular endurance) which are likely attributable to increased physical fitness [10]. Moreover, unlike other forms of traditional physical activity, TC has consistently been shown to reduce the risk of falling in elderly and frail individuals [11–13]. Possible mechanisms underlying the effectiveness of TC in reducing fall risks include enhanced fitness, proprioception and internal awareness of the participants' orientation relative to his surroundings [14, 15]. Following these promising benefits of TC exercise in elderly and frail individuals, this intervention has recently gained attention as an attractive intervention for persons with PD [16–19]. However, research on the effects of TC exercise on gait dysfunction and postural instability in persons with PD has produced conflicting results [16–20]. For instance, Li et al. [18] reported that gait velocity, functional reach test (FRT), and Unified Parkinson's Disease Rating Scale (UPDRS) were significantly improved following TC exercise (48 sessions over 24 weeks). In contrast, Hackney and Earhart [16] reported no improvements in gait velocity, stride length or functional ambulation profile after 20 sessions (over 10–13 weeks) of TC. These contradictory findings may be due, in part, to the wide variability of TC exercise regimens and heterogeneity of this patient population.

One unique feature of TC compared to other exercise modalities is that the design of TC program is more subjective, and it may influence potential benefits. For example; the choice of movements/forms taught, the style of TC (Yang, Wu, and Chen), the expertise of the instructor, and the dynamics of the exercise class, including the size and heterogeneity of individuals, can all influence outcomes. If we are to assume that TC significantly improves postural control and gait for persons with PD, its benefit should be repeatable in different settings. At the very least, we must be able to outline specific characteristics of TC which optimize the benefits of the exercise so we can recommend TC to a general PD population. However, previous studies examining the effectiveness of TC for persons with PD have mainly utilized subjective survey questionnaires [19], clinical evaluations of postural control and gait [16, 19], UPDRS [16, 18], and physical performance measures, such as the Timed Up and Go (TUG) test [19], 6-minute walk (6MW) test [16], and FRT [18]. Because these clinical assessments lack specificity to gait performance and postural stability, the efficacy of TC exercise to attenuate gait dysfunction and postural instability in persons with PD still needs to be investigated with more functionally appropriate and quantitative assessments utilizing biomechanical methodologies, such as gait initiation (GI) [12, 21, 22].

Accordingly, the purpose of this study was to investigate the effect of TC exercise on dynamic postural control during GI and gait performance in persons with PD. We conducted two separate 16-week randomized clinical trials, one which utilized a twice a week exercise schedule and the other three times a week. In both experiments, a modified Yang-style TC [23] constituted the exercise intervention while individuals' dynamic postural control and gait were measured before and after training using biomechanical assessments. We hypothesized that both 16-week TC programs would improve GI and gait performance and that the salient benefits of TC would be observed even when the training environment (i.e., location and instructor) and regimen (i.e., frequency) were manipulated. This study is the first TC intervention study utilizing well-established and quantitative biomechanical assessments of GI and gait performance to determine whether repeatable benefit of TC can be provided to persons with PD.

Methods

This study comprised two independent randomized controlled trials conducted at a metropolitan area (Project 1: Emory University in Atlanta, GA, USA) and a suburban area (Project 2: University of Florida in Gainesville, FL, USA) (Fig. 1).

Participants

A total of 45 participant volunteers across projects signed an informed consent approved by each University's Institutional Review Board. Of these, 21 were recruited in Project 1 (see Fig. 1 (a)), and 24 were recruited in Project 2, (see Fig. 1 (b)). All participants were diagnosed as having idiopathic PD by a fellowship trained movement disorders neurologist using standard criteria. Participants were excluded if they had: (1) any history or evidence of neurological deficit other than PD, (2) dementia, determined by a Mini Mental Status Examination score of $\leq 26/30$ [24], (3) inability to walk independently, (4) previous training in any forms of TC or current participation in any structured exercise program equating to greater than 20 minutes per week, or (5) inability to understand the protocol.

Intervention

The individuals randomly assigned to the TC groups participated in 60-minute TC sessions for 16 consecutive weeks. The TC participants in Project 1 ($n=12$) practiced TC forms twice a week in the exercise studio at Emory University's specialty geriatric care facility (Fig. 1(a)) and the participants in Project 2 ($n=15$) participated at University of Florida's Living Well facility three times a week (Fig. 1(b)). Exercise groups were kept small ($n \leq 5$) to promote intensive TC master/student interaction.

The TC interventions consisted of the first eight movements of the Yang-style [23] short forms. The forms emphasized components of movement typically limited in the elderly and more seriously affected in PD. Specifically, the progression of exercises involved a gradual reduction of the base of standing support until a single limb stance is achieved (the most advanced form), increased body and trunk rotation, and reciprocal arm movements that incorporate controlled breathing. In both experiments, TC instructions were provided by established and internationally-recognized TC masters in collaboration with clinicians knowledgeable about PD.

The individuals randomly assigned to the Control group in Project 1 practiced a 60-minute Qi-Gong meditation (Qi-Gong Control, $n=9$, see Fig. 1(a)). Qi-Gong is a Chinese form of "meditation in stillness" and involves a series of exercises in "energy discipline" [25]. The Qi-Gong treatments emphasized prolonged, intense contemplative, or deep meditation. Qi-Gong served as an active placebo/contact control in Project 1. In Project 2, the individuals

assigned to non-contact Control group did not participate in any interventions (Control, n=9, see Fig. 1 (b)).

Procedures

All participants in both experiments visited the laboratory both before and after the assigned intervention period for the evaluations of their GI, gait performance and parkinsonian disabilities. All participants were tested at the same time of day for both pre- and post-intervention evaluations at a time when they reported they were fully responding to their antiparkinsonian medication. Both evaluations in each participant were conducted by the same evaluators who were blinded to group assignment. Prior to the evaluation, participants were fitted with retroreflective markers according to a modified Helen Hayes marker set [26].

In Project 1, ground reaction forces were collected at 300 Hz from a force platform (Bertec Corp., Columbus, OH) mounted flush with the surface of an 8m walkway. Kinematic data were collected at 60 Hz by a six-camera 3D optical motion capture system (Peak Performance, Englewood, CO). All data were time synchronized in the Peak Motus analysis system.

In Project 2, ground reaction forces were collected at 360 Hz from a force platform (Bertec Corp., Columbus, OH) mounted flush with the surface of an 8m walkway. Kinematic data were collected at 120 Hz by a twelve-camera 3D optical motion capture system (VICON, Oxford, UK). The systems used at each site are widely used in laboratory settings and the difference between two systems in terms of data outcome was negligible.

Gait Initiation—In both projects, participants performed at least five GI trials at a self-selected speed. The initial position of the feet was self-selected and maintained for all experimental trials. These GI trials began while the participants stood in a relaxed position. Upon hearing a verbal signal, participants initiated walking and continued walking for several steps.

Gait—In both projects, participants performed a minimum of eight gait trials at self-selected speed in response to a verbal signal. A starting position was selected on one side of the walkway so participants could walk at their steady gait speed when entering the capture volume. To avoid any possible influence of acceleration and/or deceleration phase, data were collected from two middle strides representing the participants' steady gait pattern.

Outcome measures

All data collection, processing and reduction for GI and gait analysis at both sites were done by study team members blinded to group assignment.

Gait Initiation—During GI, anticipatory postural adjustments (APAs) function to initially move the center-of-pressure (COP) backward and towards the swing limb (i.e., the initial stepping limb) prior to an initial heel-off of the swing limb [21]. Evaluating APAs during GI has shown to be effective to evaluate individuals' dynamic postural control [12, 21, 22]. Specifically, posterior COP movement generates forward momentum needed to initiate gait, whereas lateral movement aids in generation of the movement of the center-of-mass towards the stance foot in preparation for stepping [21]. Previous studies revealed that with advancing age and disability there is a reduction in the magnitude of the posterior and lateral COP displacement during this time period [12, 22]. Hence, the primary GI outcome variables in this study were: (1) the magnitude of the posterior and lateral COP displacement (S1DisAP and S1DisML, respectively) and (2) the mean COP velocity in posterior and

lateral directions (S1VelAP and S1VelML, respectively) prior to an initial heel-off of the swing limb. Positive values of both displacement and velocity on the AP and ML directions correspond to posterior direction and the direction toward the swing limb, respectively. Data reduction procedures and the GI outcome measures presented here are described in greater details elsewhere [12, 22].

Gait—The gait cycle (GC) was defined as the time interval between initial heel-strike of the supporting limb and the subsequent heel-strike of the same limb. The primary spatiotemporal gait outcome variables were (1) cadence, (2) gait velocity, (3) step length, (4) step duration, (5) swing time (% of GC), (6) double limb support time (% of GC), and (7) gait asymmetry, calculated based on the marker data using the standard definitions, described in greater details elsewhere [27, 28].

Clinical motor score—The 14-item Part III of the UPDRS was conducted by movement disorders neurologists blinded to the intervention to assess participants' severity of PD-related motor symptoms. Movement disorders neurologists blind to the intervention assessed participants' severity of PD-related motor symptoms using the 14-item Part III of the UPDRS

Statistical analysis

A one-way between-groups analysis of covariance (ANCOVA) was conducted to evaluate the effect of TC exercise by comparing the experimental and control group (Project 1: TC versus Qi-Gong Control group, Project 2: TC versus Non-contact Control group) in both experiments, separately. The ANCOVA model is more powerful to detect changes from baseline than ANOVA or a t-test of change scores [29]. The magnitude of the pre-intervention value for each dependent variable was used as a covariate to control for the baseline bias. Effect size (partial η^2) was computed to evaluate the strength of difference between groups. In case the assumptions for ANCOVA were violated, absolute change scores (difference between post-intervention and pre-intervention value) were alternatively calculated and compared between groups by Mann-Whitney's U test. Pearson's correlation coefficient (r) was used to determine effect size for this case. The level of significance was set as $p < 0.05$.

Results

The demographic and baseline performance data in Projects 1 and 2 are shown in Table 1(a) and (b), respectively. No significant differences were reported between groups in any demographic or baseline variables ($p > 0.05$).

Gait Initiation

Pre and post-intervention means of all outcome measures from the GI evaluation in Projects 1 and 2 are displayed in Table 2(a) and 3(a), respectively. The statistical analyses for both experiments failed to detect a significant difference between groups, except for S1DisML in Project 1 ($p < 0.01$, $\eta^2 = 0.39$). Specifically, the individuals in Qi-Gong Control group significantly shifted their COP more toward the initial swing limb after the 16-week period when compared to the TC group. The same trend was observed in Project 2, but it did not reach significance ($p = 0.06$, $\eta^2 = 0.15$).

Gait

Pre and post-intervention means of all outcome measures in gait evaluation in Projects 1 and 2 are described in Table 2(b) and 3(b), respectively. The statistical analyses did not detect any significant difference between groups in any variable of interest.

Clinical motor score

Pre and post-intervention means of UPDRS Part III motor scores in Projects 1 and 2 are described in Table 2(c) and 3(c), respectively. No significant difference was observed between groups.

Discussion

Tai Chi is often recommended for older adults with and without neurological disease as a safe and effective means to improve many mobility-related facets of aging and disease [10–13, 16–20]. However, few studies have objectively investigated biomechanical changes in postural control and gait after TC in persons with PD [16–19]. In this investigation, we evaluated the effect of TC exercise on dynamic postural control during GI and gait performance for persons with PD and the reproducibility of the benefits, if TC was actually effective. The primary finding of the present study is that TC exercises either two or three times a week did not improve GI or gait performance in these cohorts of persons with mild to moderate PD (i.e., range of 2 to 3 of Hoehn and Yahr scale).

The APAs in GI were not improved after either of the 16-week TC programs. Previously, Hass et al. [9, 12] demonstrated that 48 weeks of TC exercise could enhance the magnitude of posterior COP displacement in older adults transitioning to frailty and that 10 weeks of resistance training could significantly increase the posterior displacement in persons with PD. Furthermore, Rogers et al. [30] reported that presentation of a startling acoustic stimulus prior to GI could lead to increased posterior and lateral COP displacement in persons with PD. In the present study, however, TC exercise delivered two or three times a week for 16 weeks did not lead to an increase in the magnitude of posterior or lateral (i.e., toward swing limb) COP displacements. Thus, TC exercise of these durations did not facilitate an improvement in gait initiation performance. In contrast, Kim et al. [17] reported that ten individuals with PD showed a significant improvement (~2.7 cm) in the posterior COP displacement after participation in a 12-week TC intervention. However, the COP displacement in their study was defined as the distance between the minimum and maximum COP location under an individual foot in anteroposterior direction while the initial swing limb was in contact with the force platform, representing the time interval until the onset of toe-off of the swing limb. This temporal definition of APAs is not consistent with previous literature [12, 21, 31]; therefore, the interpretation of these findings remains unclear.

Supplementary results from the clinical and biomechanical assessment of postural control further support the notion that TC was not effective in improving balance performance. Performance on the clinically relevant FRT did not improve significantly in Project 1 (3.5cm, $p=0.38$, $\eta^2=0.06$), and this limited change was less than the minimal detectable change for FRT in the PD population, as previously reported [32]. Further, the magnitude of sway area measured by computerized posturography was not improved in Project 2 (-0.2cm^2 , $p=0.14$, $\eta^2=0.12$). These findings were consistent with the absence of improvement in dynamic postural control during GI and gait performance. Conversely, previous studies reported improvements in Berg Balance Scale, FRT, limit-of-stability test and directional postural control after TC exercise in persons with PD [16, 18]. Therefore, before recommending that TC exercise is a truly beneficial approach to improve multiple domains of postural control for persons with PD, there is a need to resolve these inconsistencies across studies regarding TC benefits.

The lack of improvement in gait-related outcome measures in the present study was consistent with a report by Hackney and Earhart [16]. In their study, no significant improvement in either forward gait velocity (0.01m/s) or stride length (-0.1m) was reported following 20 sessions of 60-minute TC exercise. Further, they did not observe significant

improvements in TUG performance or backward walking profile, including velocity and stride length. Conversely, the authors did observe a significant improvement in 6MW (44m) and UPDRS (-1.5pts), yet this limited improvement in UPDRS does not appear to be clinically important [33]. More recently, Li et al. [18] reported a positive effect of the same number of 60-minute TC sessions as our present study. In their case-control study with three groups (TC, resistance-training (RT), and stretching exercise control), they observed a significant improvement (9.1%) in gait velocity when compared to stretching exercise controls. However, their RT participants also improved gait velocity to the same extent as the TC group. This group [18] also reported that both RT and TC participants significantly increased knee flexion/extension torque when compared to controls; thus the increase in gait velocity may indicate that improvements might be predicated on increased muscular strength of the lower limb rather than solely on neuromuscular control in gait. Considering the constructs of TC, which are believed to enhance proprioceptive inputs [14] and internal awareness of the practitioner's orientation to his environment [15], gait velocity alone may not fully capture the influence of TC on the parkinsonian deficits affecting gait performance. Furthermore, limited change in gait velocity and UPDRS motor score observed in the present study and the inconsistency across previous TC studies in PD also suggest that the effect of TC in improving locomotor control in persons with PD remains inconclusive. Nonetheless, given that many previous studies consistently reported positive effects of other interventions, such as treadmill training in improving gait velocity [34, 35], stride length [34] and UPDRS measures [34, 35] in persons with PD [36], TC may not be considered the best consistent approach to improve gait in persons with PD. Or at least for now, TC has not been proven to provide advantageous benefits over the other currently-available interventions for PD to attenuate gait dysfunction and postural instability.

One limitation of TC exercise as an intervention for persons with PD is the difficulty of controlling intensity of the exercise for an individual as well as the quality and consistency of the instruction given. Since TC exercise is usually taught in a class, providing a subject-specific training protocol is difficult; rather, TC typically consists of one generalized protocol applied to all participants within the study/class. Designing an optimal exercise regimen and duration for all participants may be challenging, especially in diseased populations with large between-subject differences, such as the case in PD. In this study, we conducted two independent experiments at different sites utilizing nationally and internationally-respected instructors. The strength of this study is that we included variability (i.e., frequency, class size, and location) and subjectivity (i.e., different instructors) of TC exercise to replicate a practical environment that participants are likely to experience in their communities. The combined results from both experiments indicate that 16 weeks of class-based TC exercise is not effective in improving dynamic postural control during GI or gait performance in persons with PD.

A potential limitation of the present study is the small sample size of the groups at each site. However, we perceived that this low student to instructor ratio improves learning of the TC forms as well as patient safety. Regardless, even if we combine the two TC intervention groups (n=27) and compare the findings to those of a combined control group (n=18), the TC group showed no significant improvement in any outcome variables. Assuming TC was effective, based on sample size calculations from our observed data, we would need 265 participants to make the differences observed here statistically significant between groups. Considering this retrospective power analysis, we speculated the effect of TC was ineffective or at least very limited in attenuating gait dysfunction and postural instability in person with PD.

The results of our study suggest that the use of short-term TC exercise for persons with PD should not be considered an effective means to improve dynamic postural control during GI

and gait. A participant-specific TC exercise regimen or perhaps a more intensive or longer duration protocol might be needed to provide a benefit to persons with PD; but may be less practical for community implementation. We cannot rule out the possibility that other outcome measures not used here may be more sensitive to the potential benefits of TC in this population. Future TC studies in PD may need to realign participant inclusion/exclusion criteria so that potential inconsistencies across benefits derived from TC training would be less likely due to the heterogeneity within a wide spectrum of PD participants. With such a consideration in mind, the relationship between the specifics of the TC intervention and the biomechanical changes might become more apparent and less varied.

Acknowledgments

This study was supported by National Institutes of Health (grant nos. 5R03HD054594 & 5R01AT000612).

References

1. McDermott MP, Jankovic J, Carter J, Fahn S, Gauthier S, Goetz CG, et al. Factors predictive of the need for levodopa therapy in early, untreated Parkinson's disease. The Parkinson Study Group. *Arch Neurol*. 1995; 52:565–70. [PubMed: 7763203]
2. Melton LJ, Leibson CL, Achenbach SJ, Bower JH, Maraganore DM, Oberg AL, et al. Fracture risk after the diagnosis of Parkinson's disease: Influence of concomitant dementia. *Mov Disord*. 2006; 21:1361–7. [PubMed: 16703587]
3. Hely MA, Reid WGJ, Adena MA, Halliday GM, Morris JGL. The Sydney multicenter study of Parkinson's disease: The inevitability of dementia at 20 years. *Mov Disord*. 2008; 23:837–44. [PubMed: 18307261]
4. Bloem BR, Hausdorff JM, Visser JE, Giladi N. Falls and freezing of gait in Parkinson's disease: a review of two interconnected, episodic phenomena. *Mov Disord*. 2004; 19:871–84. [PubMed: 15300651]
5. Stewart KC, Fernandez HH, Okun MS, Jacobson CE, Hass CJ. Distribution of motor impairment influences quality of life in Parkinson's disease. *Mov Disord*. 2008; 23:1466–8. [PubMed: 18546324]
6. Chen J, Devine A, Dick IM, Dhaliwal SS, Prince RL. Prevalence of lower extremity pain and its association with functionality and quality of life in elderly women in Australia. *The Journal of Rheumatology*. 2003; 30:2689–93. [PubMed: 14719214]
7. Nisenzon AN, Robinson ME, Bowers D, Banou E, Malaty I, Okun MS. Measurement of patient-centered outcomes in Parkinson's disease: what do patients really want from their treatment? *Parkinsonism Relat Disord*. 2011; 17:89–94. [PubMed: 20952243]
8. Goodwin VA, Richards SH, Taylor RS, Taylor AH, Campbell JL. The effectiveness of exercise interventions for people with Parkinson's disease: A systematic review and meta-analysis. *Mov Disord*. 2008; 23:631–40. [PubMed: 18181210]
9. Hass CJ, Buckley TA, Pitsikoulis C, Barthelemy EJ. Progressive resistance training improves gait initiation in individuals with Parkinson's disease. *Gait Posture*. 2012; 35:669–73. [PubMed: 22266107]
10. Hong Y, Li JX, Robinson PD. Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *Br J Sports Med*. 2000; 34:29–34. [PubMed: 10690447]
11. Wu G. Evaluation of the Effectiveness of Tai Chi for Improving Balance and Preventing Falls in the Older Population—A Review. *J Am Geriatr Soc*. 2002; 50:746–54. [PubMed: 11982679]
12. Hass CJ, Gregor RJ, Waddell DE, Oliver A, Smith DW, Fleming RP, et al. The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. *Arch Phys Med Rehabil*. 2004; 85:1593–8. [PubMed: 15468016]
13. Wolf SL, Barnhart HX, Kutner NG, McNeely E, Coogler C, Xu T. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies of Intervention Techniques. *J Am Geriatr Soc*. 1996; 44:489–97. [PubMed: 8617895]

14. Li JX, Xu DQ, Hong Y. Effects of 16-week Tai Chi intervention on postural stability and proprioception of knee and ankle in older people. *Age Ageing*. 2008; 37:575–8. [PubMed: 18541612]
15. Wayne PM, Kiel DP, Krebs DE, Davis RB, Savetsky-German J, Connelly M, et al. The Effects of Tai Chi on Bone Mineral Density in Postmenopausal Women: A Systematic Review. *Arch Phys Med Rehabil*. 2007; 88:673–80. [PubMed: 17466739]
16. Hackney ME, Earhart GM. Tai Chi improves balance and mobility in people with Parkinson disease. *Gait Posture*. 2008; 28:456–60. [PubMed: 18378456]
17. Kim H-D, Kim T-Y, Jae HD, Son S-T. The Effects of Tai Chi Based Exercise on Dynamic Postural Control of Parkinson's Disease Patients while Initiating Gait. *Journal of Physical Therapy Science*. 2011; 23:265–9.
18. Li F, Harmer P, Fitzgerald K, Eckstrom E, Stock R, Galver J, et al. Tai chi and postural stability in patients with Parkinson's disease. *N Engl J Med*. 2012; 366:511–9. [PubMed: 22316445]
19. Klein PJ, Rivers L. Taiji for Individuals with Parkinson Disease and their Support Partners: Program Evaluation. *J Neurol Phys Ther*. 2006; 30:22–7. [PubMed: 16630368]
20. Lee MS, Lam P, Ernst E. Effectiveness of tai chi for Parkinson's disease: a critical review. *Parkinsonism Relat Disord*. 2008; 14:589–94. [PubMed: 18374620]
21. Polcyn AF, Lipsitz LA, Kerrigan DC, Collins JJ. Age-related changes in the initiation of gait: degradation of central mechanisms for momentum generation. *Arch Phys Med Rehabil*. 1998; 79:1582–9. [PubMed: 9862305]
22. Halliday SE, Winter DA, Frank JS, Patla AE, Prince F. The initiation of gait in young, elderly, and Parkinson's disease subjects. *Gait Posture*. 1998; 8:8–14. [PubMed: 10200394]
23. China Sports Editorial Board. Simplified "Taijiquan". 2. Beijing: China Publication Center; 1983.
24. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 1975; 12:189–98. [PubMed: 1202204]
25. Sancier KM. Medical applications of qigong. *Altern Ther Health Med*. 1996; 2:40–6. [PubMed: 8795871]
26. Davis RB III, Öunpuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. *Human Movement Science*. 1991; 10:575–87.
27. Plotnik M, Giladi N, Balash Y, Peretz C, Hausdorff JM. Is freezing of gait in Parkinson's disease related to asymmetric motor function? *Ann Neurol*. 2005; 57:656–63. [PubMed: 15852404]
28. Winter, DA. The biomechanics and motor control of human gait: normal, elderly and pathological. Waterloo: University of Waterloo Press; 1991.
29. Van Breukelen GJP. ANCOVA versus change from baseline had more power in randomized studies and more bias in nonrandomized studies. *J Clin Epidemiol*. 2006; 59:920–5. [PubMed: 16895814]
30. Rogers MW, Kennedy R, Palmer S, Pawar M, Reising M, Martinez KM, et al. Postural preparation prior to stepping in patients with Parkinson's disease. *J Neurophysiol*. 2011; 106:915–24. [PubMed: 21525376]
31. Hass CJ, Waddell DE, Fleming RP, Juncos JL, Gregor RJ. Gait Initiation and Dynamic Balance Control in Parkinson's Disease. *Arch Phys Med Rehabil*. 2005; 86:2172–6. [PubMed: 16271566]
32. Steffen T, Seney M. Test-Retest Reliability and Minimal Detectable Change on Balance and Ambulation Tests, the 36-Item Short-Form Health Survey, and the Unified Parkinson Disease Rating Scale in People With Parkinsonism. *Physical Therapy*. 2008; 88:733–46. [PubMed: 18356292]
33. Shulman LM, Gruber-Baldini AL, Anderson KE, Fishman PS, Reich SG, Weiner WJ. The Clinically Important Difference on the Unified Parkinson's Disease Rating Scale. *Arch Neurol*. 2010; 67:64–70. [PubMed: 20065131]
34. Miyai I, Fujimoto Y, Ueda Y, Yamamoto H, Nozaki S, Saito T, et al. Treadmill training with body weight support: its effect on Parkinson's disease. *Arch Phys Med Rehabil*. 2000; 81:849–52. [PubMed: 10895994]
35. Herman T, Giladi N, Gruendlinger L, Hausdorff JM. Six weeks of intensive treadmill training improves gait and quality of life in patients with Parkinson's disease: a pilot study. *Arch Phys Med Rehabil*. 2007; 88:1154–8. [PubMed: 17826461]

36. Herman T, Giladi N, Hausdorff JM. Treadmill training for the treatment of gait disturbances in people with Parkinson's disease: a mini-review. *J Neural Transm.* 2009; 116:307–18. [PubMed: 18982238]

Fig. 1.
Research design flow chart of the present study.

Table 1

Mean values (SD) of demographic and clinical characteristics of the study participants at baseline.

	(a) Project 1		(b) Project 2	
Group	Tai Chi	Qi-Gong Control	Tai Chi	Non-Contact Control
Sample size	12	9	15	9
Age (year)	64 (13)	68 (7)	66 (11)	66 (7)
Gender M/F	7/5	7/2	7/8	7/2
Height (cm)	172.3 (9.1)	174.5 (6.9)	166.7 (10.5)	168.8 (8.4)
Mass (kg)	79.5 (16.4)	82.2 (11.7)	76.2 (14.3)	74.2 (7.2)
Disease Duration (year)	7 (7)	12 (7)	8 (5)	5 (3)
HY scale	2.3 (0.4)	2.2 (0.4)	2.4 (0.6)	2.4 (0.4)
UPDRS Motor	21.1 (6.8)	24.1 (5.7)	23.1 (6.0)	23.1 (4.8)

Abbreviations: UPDRS, Unified Parkinson's Disease Rating Scale; HY scale, Hoehn and Yahr scale.

Table 2

Mean values (SD) of pre- and post-intervention outcome measures in Tai Chi and Qi-Gong Control group in Project 1.

	Tai Chi		Qi-Gong Control		Adjusted mean / median difference(95%CI)	p	Effect size
(a) <u>GI</u>							
S1 DisAP (cm)	Pre	Post	Pre	Post			
	3.01 (1.57)	2.72 (1.17)	2.74 (0.90)	3.54 (1.56)	-0.91(-2.00 to 0.18)	0.10	0.14 (Medium)
*S1 DisMIL (cm)	3.35 (2.02)	3.58 (2.67)	2.54 (0.92)	3.96 (1.17)	-1.36(-2.2 to -0.51)	0.01	0.39(Large)
S1 VelAP (cm/s)	4.21 (3.06)	4.24 (2.26)	3.33 (3.58)	1.61 (3.19)	1.63(-1.50 to 4.77)	0.29	0.06 (Small)
§S1 VelMIL (cm/s)	3.59 (2.24)	4.23 (3.22)	2.92 (2.35)	4.33 (3.09)	-1.19(-4.49 to 1.50)	0.28	-0.25 (Small)
(b) <u>Gait</u>							
Cadence (step/min)	109 (12)	110 (15)	108 (10)	110 (8)	-1.15(-9.30 to 7.00)	0.77	0.01 (Small)
Gait velocity (m/s)	1.08 (0.15)	1.09 (0.21)	1.10 (0.31)	1.14 (0.27)	-0.04(-0.19 to 0.12)	0.63	0.02 (Small)
Step length (m)	0.60 (0.07)	0.59 (0.08)	0.61 (0.15)	0.62 (0.14)	-0.02(-0.07 to 0.04)	0.55	0.02 (Small)
Step Duration (s)	0.56 (0.06)	0.55 (0.07)	0.56 (0.05)	0.55 (0.04)	0.01(-0.03 to 0.05)	0.54	0.02 (Small)
Swing time (%GC)	50.03 (3.72)	48.98 (1.06)	48.59 (1.49)	48.74 (1.69)	0.14(-1.29 to 1.57)	0.84	0.00 (None)
§Double limb support time (%GC)	10.76 (3.95)	11.47 (1.86)	13.10 (3.19)	12.02 (3.49)	1.17(-0.29 to 2.84)	0.10	-0.37 (Medium)
§Gait asymmetry (a.u.)	14.41 (22.87)	7.27 (6.32)	11.98 (15.74)	9.31 (6.05)	-6.02(-14.84 to 3.51)	0.18	-0.31 (Medium)
(c) <u>Clinical Score</u>							
§UPDRS Motor (a.u.)	21.1 (6.8)	22.0 (8.0)	24.1 (5.7)	20.7 (7.0)	1.39(-3.12 to 5.89).	0.46	0.03 (Small)

§ indicates data were not normally distributed or the parallelism assumption for ANCOVA was violated; thus, absolute change scores were alternatively compared between groups by Mann-Whitney U test and effect size was determined by Pearson's correlation coefficient.

* indicates a significant difference was observed between Tai Chi and Qi Gong Control group ($p < .05$).

Abbreviations: CI, Confidence interval; GC, Gait cycle; S1DisAP, posterior COP displacement during S1 phase; S1DisML, lateral COP displacement toward the initial swing limb during S1 phase; S1VelAP, the mean COP velocity in posterior direction during S1 phase; S1VelML, the mean COP velocity in lateral direction toward the initial swing limb during S1 phase; UPDRS, Unified Parkinson's Disease Rating Scale.³

Table 3

Mean values (SD) of pre- and post-intervention outcome measures in Tai Chi and Non-Contact Control group in Project 2.

	Tai Chi		Non-Contact Control		Adjusted mean / median difference (95%CI)	p	Effect size
(a) <u>GI</u>	Pre	Post	Pre	Post			
S1 DisAP (cm)	2.03 (1.53)	1.55 (1.40)	2.02 (1.24)	2.12 (1.32)	-0.57 (-1.54 to 0.40)	0.24	0.06 (Small)
*S1 DisML (cm)	2.16 (1.15)	1.63 (1.13)	1.42 (1.33)	1.97 (1.41)	1.43 (0.90 to 1.96)	0.06	0.15(Medium)
§S1 VelAP (cm/s)	6.04 (4.11)	5.22 (3.24)	6.08 (4.63)	5.82 (4.12)	-0.18 (-4.51 to 3.29)	0.89	-0.03 (None)
§S1 VelML (cm/s)	6.69 (4.71)	4.60 (2.74)	4.00 (2.90)	4.41 (3.95)	-0.92 (- to 0.45)	0.26	-0.23 (Small)
(a) <u>Gait</u>							
Cadence (step/min)	112 (10)	111 (10)	110 (10)	111 (10)	-2.28 (-6.14 to 1.59)	0.23	0.06 (Small)
Gait velocity (m/s)	1.01 (0.29)	1.02 (0.26)	1.09 (0.16)	1.11 (0.17)	-0.02(-0.10 to 0.06)	0.58	0.01 (Small)
Step length (m)	0.54 (0.13)	0.55 (0.11)	0.58 (0.06)	0.59 (0.06)	-0.01(-0.04 to 0.03)	0.70	0.01 (None)
Step Duration (s)	0.54 (0.05)	0.54 (0.06)	0.44 (0.13)	0.45 (0.11)	0.00(-0.03 to 0.03)	1.00	0.00 (None)
Swing time (%GC)	37.29 (3.82)	37.69 (4.59)	38.97 (2.87)	39.01 (2.72)	0.28 (-1.66 to 2.52)	0.77	-0.07 (None)
§Double limb support time (%GC)	24.95 (6.97)	24.65 (8.84)	22.45 (5.28)	22.59 (4.92)	-0.49(-4.00 to 3.00)	0.85	-0.04 (None)
§Gait asymmetry (a.u.)	3.39 (1.86)	4.41 (2.80)	4.65 (3.84)	5.11 (3.35)	-0.36 (-2.97 to 2.25)	0.78	0.00 (None)
(b) <u>Clinical Score</u>							
§UPDRS Motor (a.u.)	23.1 (6.0)	23.4 (4.7)	23.1 (4.8)	22.0 (5.6)	1.44 (-3.00 to 6.00)	0.48	0.02 (Small)

§₁ indicates data were not normally distributed or the parallelism assumption for ANCOVA was violated; thus, absolute change scores were alternatively compared between groups by Mann-Whitney U test and effect size was determined by Pearson's correlation coefficient.

* indicates a significant difference was observed between Tai Chi and Qi Gong Control group ($p < .05$).

Abbreviations: CI, Confidence interval; GC, Gait cycle; S1DisAP, posterior COP displacement during S1 phase; S1DisML, lateral COP displacement toward the initial swing limb during S1 phase; S1VelAP, the mean COP velocity in posterior direction during S1 phase; S1VelML, the mean COP velocity in lateral direction toward the initial swing limb during S1 phase; UPDRS, Unified Parkinson's Disease Rating Scale.³