Internet Journal of Allied Health Sciences and Practice

Volume 20 | Number 3 Article 2

June 2022

The Effect of Tai Chi on Dynamic Balance in Younger Adults: Implication for Physical Therapy Practice

Anthony O'Neill
Augusta University, mt.toneyoneill@gmail.com

Debra A. Beazley
University of Lynchburg, dabeazley@gmail.com

Lori Bolgla
Augusta University, lbolgla@augusta.edu

The Effect of Tai Chi on Dynamic Balance in Younger Adults: Implication for Physical Therapy Practice

Abstract

Purpose: The objective of this study was to investigate the effect of Tai Chi on the dynamic balance in younger, active community-based adults with no history of lower extremity injury or balance problems. **Methods:** Fourteen subjects (4 males / 10 females; age 23.6 + 6.2 years-old; height 166.5 ± 11.1 cm; weight 75.9 ± 19.3 kg) completed a 13-week undergraduate Tai Chi course. Dynamic balance was assessed at the beginning and the end of the course using the Y-Balance test. **Results:** Post-hoc testing showed significant improvements in anterior (P=0.007) and posterior lateral (P=0.003) reach distances with a Cohen's d at 0.54 and 0.71 for the anterior and posterior lateral, respectively with significant improvement in right composite compared to left composite (P<0.0001). Cohen's d was 0.51 and 1.38 for the left and right composite score, respectively. **Conclusions:** These findings suggest that Tai Chi may be useful as an exercise regimen to increase anterior and posterior lateral dynamic balance in balance-dependent activity as measured by the Y Balance Test. The authors champion that Tai Chi may be a useful addition for a physical therapy treatment plan, preventative exercise plan, or wellness program to increase anterior and posterior lateral dynamic balance.

Author Bio(s)

Anthony O'Neill, DPT, RDN, LMT is a licensed physical therapist, medical dietician, and massage therapist. He currently is practicing as an outpatient physical therapist in California and is pursing a Yoga Teacher Training Certificate. He is a recent graduate of the Doctor of Physical Therapy Program at Augusta University.

Debra Beazley, PT, MBA, PhD is an Associate Professor in the Physical Therapy Program at the University of Lynchburg in Lynchburg, Virginia and was previously an Associate Professor at Augusta University. She is a licensed physical therapist in Georgia and Virginia.

Lori Bolgla, PT, MAcc, ATC is the Kellett Chair in Research in the College of Health Sciences and professor in the Graduate School, the Medical College of Georgia, and the Department of Physical Therapy at Augusta University. She is a licensed physical therapist in Georgia.

Acknowledgements

The authors would like to acknowledge Dr. Hailei Zhao from the Augusta University Confucius Institute and the Shanghai University of Traditional Chinese Medicine in Shanghai, China for the support given to this research project.

Abstract
The objective of this study was to investigate the effect of Tai Chi on the dynamic balance in younger, active community-based adults with no history of lower extremity injury or balance problems. Fourteen subjects (4 males / 10 females; age 23.6 ± 6.2 years-old; height 166.5 ± 11.1 cm; weight 75.9 ± 19.3 kg) completed a 13-week undergraduate Tai Chi course. Dynamic balance was assessed at the beginning and the end of the course using the Y-Balance test. Post-hoc testing showed significant improvements in anterior (P=0.007) and posterior lateral (P=0.003) reach distances with a Cohen's d at 0.54 and 0.71 for the anterior and posterior lateral, respectively with significant improvement in right composite compared to left composite (P<0.0001). Cohen's d was 0.51 and 1.38 for the left and right composite score, respectively. These findings suggest that Tai Chi may be useful as an exercise regimen to increase anterior and posterior lateral dynamic balance in balance-dependent activity as measured by the Y Balance Test. The authors champion that Tai Chi may be a useful addition for a physical therapy treatment plan, preventative exercise plan, or wellness program to increase anterior and posterior lateral dynamic balance.

Key words: dynamic balance, physical therapy, Tai Chi, Y Balance Test, young adults

INTRODUCTION

Dynamic balance is the ability to maintain an upright posture through a shifting center of gravity. This is an important skill for any movement-based activity considering ranges in movement activity from as simple as walking to as complex as ballet. Dynamic balance requires lower extremity strength, flexibility, proprioception, and neuromuscular control, as well as a properly functioning peripheral and central nervous system.[1] A healthy and integrated neurological and musculoskeletal system is needed for a strong dynamic balance. Poor dynamic balance, due to impairments or deficiencies in the neuromuscular or muscular systems, may reflect suboptimal performance and lead to injuries.[2,3] Decreased function of dynamic balance in deconditioned individuals may lead to decreased ability to perform activities of daily living.[4,5] Athletes that underperform on dynamic balance tests can be at higher risk for sustaining a lower extremity injury, while older adults with inadequate dynamic balance are at higher risk for falls, serious injury from the fall, and death.[2,4-6] Radu and Rata determined in their research of young adults that physically active young people have better postural balance than do the sedentary ones, as scored with the Balance Error Scoring system suggesting the potential balance decline of inactive young adults. [7] Therefore, improving or preventing the loss of dynamic balance is important for all individuals throughout the lifespan.

An exercise asserted to have the effect of improving dynamic balance, dynamic standing, and lead to balance improvements during exercise, sporting activities, and activities of daily living is the intervention of Tai Chi.[8] Growing in popularity as an easily adapted exercise, Tai Chi as a component of Tai Chi, Yoga, and Qi Gong is noted by the National Health Statistics Report of the Centers for Disease Control and Prevention to have a usage increase among United States adults aged 18 and over from 5.8% in 2002 to 10.9% in 2012.[9] The popularity for Tai Chi is driven in part by the ease of use as either a practitioner-driven or individualized low impact exercise. Contributing to the popularity of use by physical therapists is the research performed by Wang et al which espouses Tai Chi to have similar beneficial effects to the standard course of physical therapy treatments for specific conditions.[10]

Tai Chi is asserted to be a beneficial exercise for dynamic balance among individuals with differences in fitness level and age.[11,12] As a weight-bearing exercise consisting primarily of slow, controlled, and flowing movements combined with controlled breathing and mental concentration, Tai Chi requires no special equipment or athleticism. It can be adapted for individuals of very low function or challenging enough for those of very high function by simple modifications of the postures, such as deepening the stance or widening and lowering the body into the lunge for higher level practitioners or practicing seated for frail individuals.[13] Research conducted over the last two decades has demonstrated the usefulness of Tai Chi as a safe and effective intervention for improving dynamic balance and preventing falls in the older individual.[14, 15] Previous research of Tai Chi has emphasized improvement in balance, posture and neuromuscular control as well as joint proprioception for mostly older participants contributing toward research in improvement of gait stability and reduction in falls. Research examining specifically the effects of Tai Chi on joint proprioception has alluded to the efficacy of long term Tai Chi in producing improved joint stability proprioception and stability in weight shifting.[16] Additional research conducted by Wang et al supports the idea of Tai Chi to be equally beneficial as a proprioceptive exercise program in improving neuromuscular function of the ankle in an older population.[17] Additionally, research has shown a contribution of Tai Chi to the improvement of conditions such as chronic obstructive pulmonary disease, stress, anxiety, hypertension, chronic pain, and low bone mineral density among others.[13, 15] However, very few studies investigate the effects of Tai Chi in a younger, generally healthy recreationally active community-based population. One study that examined younger adults, the research of Radu and Rata demonstrated that balance deficits may exist in younger adults with a sedentary life style suggesting that deficits in balance may exists in a self-reported active community-based population.[7] This research project assumes a beneficial effect of a 13-week Tai Chi course for community-based participants who are self-reported as active young adults with an understanding that life style while not measured may present on a spectrum across the group from more sedentary to more active.

The Y Balance Test (YBT), a commercially available tool that is commonly used for clinical assessment of dynamic balance, was developed to standardize the modified Star Excursion Balance Test (SEBT). YBT was designed as an abbreviated version of the SEBT improving efficiency to three directions: anterior (ANT), posterolateral (PL), and posteromedial (PM).[18] The YBT composite score (CS) is calculated by summing the three reach directions and normalizing to lower extremity length. Asymmetry is the difference between right and left limb reach. The SEBT has been suggested to predict which individuals are at risk for lower extremity injury. When evaluating the composite score, Plisky et al found female athletes with a composite reach of less than 94% of limb length were at risk of an injury.[19] Research has shown that greater than 4 cm of ANT asymmetry during the SEBT suggests a prediction of individuals at risk for injury and a CS of less than 89% of limb length increases lower extremity injury risk that is 3.5 times greater.[2] Steffen et al reported that adherence to a neuromuscular training program improved performance on the SEBT and decreased risk of injury in female youth soccer players.[20] Important to the research of this study of male and female participants, researchers have demonstrated no difference between sexes in performance of the YBT when small samples are used.[21, 22]

The hypothesis of this study was that a short course of Tai Chi intervention would increase performance on the Y Balance Test (YBT) for these subjects in the anterior, posterior lateral, and posterior medial directions. The authors assert that if Tai Chi is shown to be beneficial for improving dynamic balance in a younger population, it may be a way to augment dynamic balance training and reduce the likelihood of potential injury in younger, community-dwelling individuals. The ease of performance of Tai Chi may empower the patient and physical therapist to use Tai Chi as an exercise that can be performed anywhere with no equipment and easily adjusted to be practiced throughout the entire lifespan.

RESEARCH DESIGN

Participants

Participants for the Internal Review Board approved study were recruited via convenience sampling through a for-credit undergraduate Tai Chi course. The course professor was not involved in the research project and there was no course incentive for the participant's involvement in the study. Participants self-disclosed to be healthy and recreationally active in the community. The participants reported to have no history of lower extremity injury or surgery or pre-existing balance issues. Participants with these issues were excluded from the study. The researchers met with the students participating in the class at the end of the second-class session, and explained the purpose of the study and the process of the study. Volunteers were solicited for the study during this session, the informed consent as well as demographic data were completed, and initial baseline measurements were taken. Sixteen students volunteered to participate in the study, however, two were lost to follow-up, meaning these subjects declined to participate in the final measurements. As noted in Table 1, the final fourteen subjects included four men and ten women (mean age 23.56 $\pm$ 6.17 years-old; height 166.5 ± 11.1 cm; weight 75.9 ± 19.3 kg). The final measurements were taken at the conclusion of the semester during the last night of the course.

Outcome Measure

The Y Balance Test was used to assess balance in accordance with procedures described by Hertel et al.[23] The YBT requires a piece of equipment composed of a raised platform with three calibrated pipes jutting out in the ANT, PL, and PM directions. Each pipe is marked in centimeters with a sliding piece that the test taker slides with the reaching limb to indicate reach distance. Plisky et al reported good-to-excellent interrater (ICC=0.99-1.00) and intra-rater reliability (ICC=0.85-0.91).[3] Prior research has determined a minimal clinical importance difference (MCID), or the smallest difference in score which a patient would perceive as beneficial for a change in intervention management, for the YBT CS at 3.5%.[24,25]

Table 1. Subject Demographics

Subject	Sex	Age	Height (cm)	Weight (kg)	BMI
1	M	20	180.3	90.8	27.9
2	F	21	154.9	43.1	18.0
3	F	22	162.6	54.9	21.0
4	F	21	160.0	58.6	23.0
5	M	20	187.9	86.3	24.4
6	F	24	167.6	72.6	25.9
7	F	24	170.2	72.6	25.1
8	F	44	167.6	113.0	40.2
9	F	19	165.1	72.6	26.7
10	F	29	162.5	90.8	34.4
11	M	21	182.8	81.7	24.4
12	M	20	177.8	86.3	27.3
13	F	22	165.1	85.4	31.3
14	F	19	152.4	42.5	18.3

Design and Setting

This pilot study used a quasi-experimental, pre- and post-test research design measuring dynamic balance following a 13-week Tai Chi program. The independent variable of the study was the Tai Chi method which consisted of the Simplified 24-Posture

Routine.[26] The dependent variable of the study was the change score from the start to the end of the course on the YBT excursion measured bilaterally. The Tai Chi course met two times per week for a total of 13 weeks (26 sessions). Additionally, there were two self-practices and two meetings for testing. Each session comprised a 5-minute warm-up that included gentle circular movements of the neck, shoulders, wrists, hips, knees, and ankles. Warm-up was followed by 45 minutes of Tai Chi instruction. The class was taught by Dr. Hailei Zhao, a visiting professor from Shanghai University of Traditional Chinese Medicine, in partnership with the Augusta University Confucius Institute. Dr. Zhao, a Tai Chi instructor and Doctor of Traditional Chinese Medicine had nearly 20 years of clinical and academic experience.

Procedures

Subjects were instructed in the process for the YBT as well as demonstrated the process for the test. After being instructed in the YBT, each subject performed one practice trial that included movement in each direction bilaterally. Practice was followed by three test trials in each direction bilaterally. Reach distance was recorded to the nearest ½-cm. The results of each of the three trials was averaged and normalized to limb length. These calculations comprised an individual (INDIV) direction reach score. Additionally, all reach distance values for each limb were combined and averaged to obtain a composite (COMP) score using the following equation, as defined by Plisky et al: *[{(avg. ANT + avg. PM + avg. PL)/3} / limb length] x 100*. [6]

Data Analysis

Statistical analyses were conducted using Statistical Package for Social Science, version 25 (SPSS Inc, Chicago, IL, USA). The distances of the three trials in each reach direction were averaged and normalized to limb length using the formula: *norm (%) = avg distance (cm)/leg length (cm) x 100*. The normalized data was used to perform a 2 (side) X 3 (direction) X 2 (time) ANOVA with repeated measures to compare how these factors influenced changes in individual reach (INDIV) direction. Additionally, all reach distance values for each limb were combined and averaged to obtain a composite (COMP) score. COMP scores provide a more overarching view of the subjects. COMP scores were calculated using the following equation: *COMP = (avg. ANT + avg. PM + avg. PL)/3 x limb length x 100*. A 2 (side) X 2 (time) ANOVA with repeated measures was used to compare changes in COMP. The *P*-value was 0.05 and corrected using the Bonferroni procedure. The Bonferroni procedure protects against Type I error (false positive) by adjusting the *P*-value of each individual comparison to give the overall probability of 0.05.[27] Lastly, effect sizes were calculated using (Cohen's *d*) to determine clinically-meaningful changes.[27] Cohen's *d* was 0.54 and 0.71 for the ANT and PL, respectively. At baseline, there was no difference in mean reach distances between the left and right sides; however, an interaction effect existed between side and time for COMP. Post-hoc testing showed a significant improvement in right COMP compared to left COMP (*P*<0.0001). Cohen's *d* was 0.51 and 1.38 for the left and right COMP, respectively.

RESULTS

Sixteen students volunteered to participate in the study, however, two were lost to follow-up. Subjects included four men and ten women (mean age 23.56 $\pm$ 6.17; height 166.5 ± 11.1 cm; weight 75.9 ± 19.3 kg). All subjects were between the ages of 19 and 24, except one participant that was 28 and one that was 44 years old. All participants were undergraduate students at Augusta University enrolled in an introduction to Tai Chi course for college credit. The average attendance rate for the course as provided by the professor was 90% for the participants in the sample; individual attendance rates was not provided by the professor to the researchers.

Post-hoc testing showed significant improvements in ANT (*P*=0.007) and PL (*P*=0.003) reach distances, but not in the PM (P=0.326) reach distance (Table 2). Cohen's *d* was 0.54 and 0.71 for the ANT and PL, respectively. At baseline, there was no difference in mean reach distances between the left and right sides; however, an interaction effect existed between side and time for COMP. Post-hoc testing showed a significant improvement in right COMP compared to left COMP (*P*<0.0001) (Table 3). Cohen's *d* was 0.51 and 1.38 for the left and right COMP, respectively. Based on prior research, MCID of 3.5% is exceeded. Minimal improvement for these composite scores tabulated at 101 cm is exceeded on the left (102.7 cm) and right (109.7 cm) suggesting the changes made in scores show merit toward a beneficial use of this intervention.

Table 2

Mean Reach Pre- and Post-Intervention

Direction	(L) Mean Pre-Test Distance (cm)	(R)Mean Pre-Test Distance (cm)	Avg. Mean Pre-Test Distance (cm)	(L) Mean Post-Test Distance (cm)	(R) Mean Post-Test Distance (cm)	Avg. Mean Post-Test Distance (cm)	P
ANT	72.9	72.3	72.6	76.1	75.5	75.8	.007
PM	109.7	110.3	110.0	111.0	112.4	111.7	.326
PL	112.5	112.6	112.1	119.2	119.0	119.1	.003

Table 3
Composite scores pre- and post-intervention.

Side	Pre-Intervention COMP Score (%)	Post-Intervention COMP Score (%)	Mean Difference (Post-Pre)	P Value
Left	98.4 ± 7.9	102.1 ± 6.5	3.76	.014
Right	98.4 ± 8.2	109.7 ± 8.2	11.31	.0001

Note: Based on prior research, MCID of 3.5% is exceeded. Minimal improvement for these composite scores tabulated at % to 101 is exceeded on the left and right and significant on the right.[24]

DISCUSSION

The purpose of this study was to examine the effects of a 13-week Tai Chi exercise program on dynamic balance in a population of younger, active community-based adults. Most of the research available on Tai Chi to date has been done in a population of older adults in the context of fall risk and chronic disease. Wang et al in a research study to compare Tai Chi to traditional physical therapy treatment for participants with a history of osteoarthritis found (Tai Chi at 2 times per week for 12-weeks) produced similar benefits to a six-week traditional physical therapy program at (2 times per week for 6 weeks with a 6-week exercise follow-up).[10] At 12 weeks, the Western Ontario and McMaster Universities Osteoarthritis Index score was substantially reduced in both groups suggesting that Tai Chi was equally beneficial for these participants.[10] Wolf et al in an early research study to compare Tai Chi effectiveness to computerized balance training found Tai Chi to impact favorably on biomedical and psychosocial indices of frailty and to have a favorable effect upon occurrence of falls.[12] Unlike these studies, this research did not compare two interventions; nor was there assumed to be a condition limiting function in this sample of younger adults. Harada et al in a study similar to this research measured standing sway for pre and post intervention in young, active adults following a 40-minute Tai Chi intervention.[29] Standing sway with double-leg-stance and single-leg-stance (eyes open and closed) testing showed a reduction in sway after the 40-minute Tai Chi class suggesting a possible improvement in balance for this group of young participants. The improvement in YBT scores for subjects of this research project suggested a meaningful improvement YBT scores after the thirteen-week intervention.

The results of this study showed overall improvements in dynamic balance, as evidenced by improved COMP scores following the 13-week Tai Chi intervention. The effect size of Tai Chi on the COMP scores was moderate on the left side and high on the right side indicating that participants had greater improvement in dynamic balance on the right lower extremity. Regarding reach directions, there were statistically significant improvements in the ANT and PL reach directions with moderate effect size. However, there was no statistically significant change in the PM reach direction. This finding may be explained by the nature of the Tai Chi form practiced. The form includes postures that involve single-leg weight bearing while reaching/stepping forward or reaching/stepping backward with the non-weight bearing leg. The forward stepping is similar to the ANT reach direction, while the backward stepping is similar to the PL reach direction of the YBT. There are no movements in this Tai Chi form that simulate the PM reach direction.

Considering the statistical significance of these results combined with moderate and high effect sizes, these results suggest that the improvements seen in dynamic balance in this population are well beyond trivial.[27] Furthermore, there may be far reaching implications, as impaired dynamic balance is a risk factor for many conditions and contributes to disability in all ages. The MCID was met bilaterally suggesting Tai Chi as a possible use for improving dynamic balance in anterior and posterior-lateral lower extremity movement. The authors of this paper advocate that Tai Chi may be beneficial in reducing the discrepancies in ANT / PL movements of the lower extremities that lead to injury. The present study suggests that Tai Chi improves dynamic balance in an active, younger adult population with no history of lower extremity injury or balance issues. Improvements in YBT scores have been associated with positive outcomes in predicting the potential for lower extremity injury risk. Considering this, Tai Chi may be a useful addition to a physical therapy treatment plan, preventative exercise, or wellness program.

Limitations

Some limitations of this study should be noted. The sample size was small with no control group. The study design did not capture a discernment or a reason for right and left COMP discrepancies. Lifestyle of this group was not measured suggesting that some of the self-reported active group may present with a more sedentary lifestyle. The intervention period was relatively short. By the end of the class, the students were able to complete the form with some cueing from the instructor, but few could perform the form in its entirety on their own.

Future Directions

Future research should focus on larger sample sizes, hand dominance, and recognition of pre-intervention fitness levels and lifestyle. A control group involved in no intervention would be useful to distinguish results from natural fluctuations in ability to

perform YBT tasks. Lastly, it is reasonable to assume that Tai Chi may have a beneficial effect on lower extremity movements that benefit from improvements in dynamic balance in anterior and posterior lateral positions. In a cross-sectional study comparing 29 older Tai Chi practitioners to healthy adults of similar age, the Tai Chi practitioners had stronger knee strength.[29] Therefore, future research controlling for the above parameters and inclusion of musculoskeletal conditions would be insightful.

In conclusion, Tai Chi is an easy to perform exercise that requires no equipment and can be modified for a wide range of fitness levels. The present pilot study suggests that Tai Chi improves dynamic balance in an active, community-based younger adult population with no history of lower extremity injury or surgery or balance deficits. Tai Chi may be beneficial in treating and preventing neuromusculoskeletal declines of the lower extremity and may be a useful component of or adjunct to physical therapy. Improvements in YBT scores have been associated with positive outcomes in multiple conditions, including chronic ankle instability, Patellofemoral Pain Syndrome, and lower extremity injury risk in young athletes.[30-33] Additionally, practicing Tai Chi throughout life may provide benefits if practiced into older age. Considering this, Tai Chi may be a useful addition to a physical therapy treatment plan, preventative exercise plan, or wellness program as a means to increase balance and decrease the risk of injury.

REFERENCES

1. O'Sullivan S B, Schmitz T J, Fulk G D. *Physical Rehabilitation* (sixth ed.). F.A. Davis Company; 2014.
2. Butler R J, Lehr M E, Fink M L, Kiesel K B, Plisky P J. Dynamic balance performance and noncontact lower extremity injury in college football players: an initial study. *Sports Health.* 2013;*5*(5):417-422.
3. Plisky P J, Gorman P P, Butler R J, Kiesel K B, Underwood F B, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. *N Am J Sports Phys Ther*. 2009;4(2):92-99.
4. Bergen G, Stevens M R, Burns, E R. *Falls and Fall Injuries Among Adults Aged ≥65 Years — United States, 2016*.
5. Bird M L, Pittaway J, Cuisick I, Rattray M, Ahuja K D. Age-related changes in physical fall risk factors: results from a 3 year follow-up of community dwelling older adults in Tasmania, Australia. *Int J Environ Res Public Health.* 2013;10(11).5989-5997.
6. Plisky P J, Rauh M J, Kaminski T W, & Underwood, F B. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 2006;36(12):911-919.
7. Radu P, Rata A. Balance performance in sedentary and active healthy young individuals – a corss sectional study. *Phys Ed Stud.* 2020;24(2):115-119.
8. Fong S M & Ng G Y (2006). The effects on sensorimotor performance and balance with Tai Chi training. *Arch Phys Med Rehabil*. 2006;87(1):82-87.
9. Clarke T, Mahin R, Barnes P, Stussman B. Use of complementary health approaches for musculoskeletal pain disorders among adults: United States, *National Health Statistics Report*. 2012:98.
10. Wang C, Schmid C, Ivesen M, et al. Comparative effectiveness of Tai Chi versus Physical Therapy for knee osteoarthritis: A randomized trial: *Ann Intern Med.* 2016;165(2):77-86.
11. Lan C, Chen S Y, Wong M K, Lai, J S. Tai Chi Chuan exercise for patients with cardiovascular disease. *Evid Based Complement Alternat Med. 2013;* 983208.
12. Wolf S, Barnhart H, Kutner, et al. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. J Am Geriatr Soc. 1996;44(5):489-497.
13. Bottomley J M. *Integrative Therapies in Rehabilitation* (C M Davis Ed. fourth ed.). SLACK Incorporated; 2017.
14. Solloway M R, Taylor S L, Shekelle P G, et al. An evidence map of the effect of Tai Chi on health outcomes. *Syst Rev.* 2016;5(1):126.
15. Wayne P M, Fuerst M L. *The Harvard Medical School Guide to Tai Chi: 12 Weeks to a Healthy Body, Strong Heart, & Sharp Mind*. Shambhala; 2013.
16. Tsang W, Hui-Chan C. Effects of Tai Chi on joint proprioception and stability limits in elderly subjects, *Med Sci Sports Exerc*. 2013.
17. Liu J, Wang X, Zheng J, et al. Effects of Tai Chi versus proprioceptive exercise program on neuromuscular function of the ankle in elderly people: A randomized controlled trial. *J Evid Based Complimentary and Altern Med*. 2012;1-8.
18. Hertel J. Sensiormotor deficits with ankle sprains and chronic ankle instability. *Clin Sports Med*. 2008;27(3):353-370.
19. Plisky P, Rauh M, Kaminski T, Underwood F. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther*. 2006:36(12):911-919.
20. Steffen K, Emery C, Romiti M et al. High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trail. *Br J Sports Med*. 2013;47(12):794-802.
21. Gribble P, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Meas Phys Educ Exerc Sci*. 2003;7(2):89-100.

22. Sabin M, Ebersole K, Martindale A, Price J, Broglio S. Balance performance in male and female collegiate basketball athletes: influence of testing surface. *J Strength Cond Res*. 2010;24(8):2073-2078.
23. Hertel J, Braham R, Hale S, Olmsted-Kramer L. Simplifying the Star Excursion Balance Test: analyses of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther.* 2006;36(3):131-137.
24. Cook C. Clinimetrics cornor: The minimal clinically important change score (MCID): A necessary pretense. *J Man Manip Ther*. 2008;16(4):E82-83.
25. Chimera N, Smith C, Warren M. Injury history, sex, and performance on the Functional Movement Screen and Y Balance Test. *J Athl Train*. 2015; 50(5):475-485.
26. Liang S, Wu W. *Simplified Tai Chi Chuan: 24 Postures with Application & Standard 48 Postur*es. YMAA Publication Center; 2014.
27. Portney L, Watkins M. *Foundation of Clinical Research: Applications to Practice (Third ed.)*. Pearson Education; 2009.
28. Sullivan G, Feinn R. Using effect size-or why the p value is not enough. *J Grad Med Educ*. 2012;4(3):279-282.
29. Harada T, Fijita T, Yamamoto S, Ishizaki F, Nitta Y, Aoi S, Ikeda H, Hiroto H, Iida T, Nitta K. Impacts of Tai chi on balance in healthy young adults. *Int Med J*. 2018;25(2):92-94.
30. Lu X, Hui-Chan C, Tsang W. Tai Chi, arterial compliance, and muscle strength in older adults. *Eur J Prev Cardiol*. 2013;20(4):613-619.
31. Chevidikunnan M, Al Saif A, Gaowgzeh R, Mamdouh K. Effectiveness of core muscle strengthening for improving pain and dynamic balance among female patients with patellofemoral pain syndrome. *J Phys Ther Sci*. 2016;28(5):1518-1523.
32. Gribble P, Hertel J, Plisky P. Using the Star Balance Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systemic review. *J Athl train*. 2012;36(3):131-137.
33. Sefton J, Yarar C, Hicks-Little C, Berry J, Cordova M. Six weeks of balance training improves sensorimotor function in individuals with chronic ankle instability. *J orthop Sports Phys Ther*. 2011;41(2):81-89.