วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 19 ฉบับที่ 1, กรกฎาคม 2562
Journal of Sports Science and Technology Volume 19, No. 1, 2019

THE EFFECT OF UNILATERAL ANKLE MUSCLE FATIGUE ON POSTURAL CONTROL IN OLDER ADULTS

Sarit SUWANMANA, Metta PINTHONG* and Weerawat LIMROONGREUNGRAT

College of Sports Science and Technology, Mahidol University, Nakhon Phathom, Thailand 73170

ABSTRACT

The aim of this study was to investigate the effect of unilateral ankle fatigue on postural control in older adults. Fourteen older adults (male = 7, female = 7) volunteered to participate in this study. Subjects (aged 65 ± 4 years) were asked to perform perturbation tests; bipedal standing followed by 15 repetitions of rapid arm raising, during pre-fatigue and post-fatigue conditions. Ankle fatigue was induced in dominant leg by preforming repetitive dorsi-and plantar-flexion exercise (120°/s) and terminated when maximum voluntary isometric contraction (MVIC) decreased to 50%. To evaluate postural control, center pressure (COP) excursion and center of mass (COM) displacement were recorded during the perturbation using 10 cameras motion capture (BTS DX 5000, BTS Bioengineering, Italy) and force platform (Kistler Instrument AG, Switzerland). Results showed that COP excursion and COM displacement in anterior posterior direction were significantly increased ($p<0.05$) after ankle fatigue (COP: Pre- vs. Post fatigue = 20.0 ± 6.4 vs. 22.2 ± 6.6); (COM: Pre- vs. Post fatigue = 7.8 ± 1.6 vs. 8.8 ± 1.5). However, no significant changes of COP and COM was observed in medial-lateral direction. It can be concluded that postural control capability during perturbation in older adults was compromised by acute unilateral ankle muscle fatigue.

(Journal of Sports Science and Technology 2019; 19(1): 49-57)

(Received: 1 May 2019, Revised: 12 June 2019, Accepted: 13 June 2019)

Keywords: Postural control / Muscle fatigue / Older adults / Center of pressure / Center of mass.

***Corresponding author**: Metta PINTHONG, PhD

College of Sports Science and Technology, Mahidol University,

Salaya campus, Phuttamonton, Nakhonpathom, Thailand, 73170

E-mail: metta.pin@mahidol.edu

INTRODUCTION

Significant changes of the human body and its function are commonly observed when human reach their elderly years in particularly the reduction in muscle strength, endurance, mobility, and impairment of postural control[1]. It has been shown that deterioration of ankle muscle strength causes significantly impact on the postural movements[2], and these impairments can commonly increase risk of falling among older adults[3].

Normally, the ability to maintain postural stability depends on coordination of visual, vestibular, and somatosensory systems[4-6]. If one of these sensory components is changed or impaired, postural sway is subjected to increase. Therefore, an enhancement of postural control or improvement of the capability to keep center of mass (COM) of the body over base of support during quiet standing, movement, and especially during the perturbation when balance is disturbed is important for reducing the risk of falling[4, 7]. To preserve a state of balance, the COM and the center of mass (COP) position, defined as the point location of the ground reaction force vector on the surface of a force platform on which a person standing are constantly regulated[8]. Several studies have shown in non-fatigue condition that larger displacements of the body's COM and COP in healthy older adults following a perturbation compared with the young adults were observed[9-11]. These results supported that the ability to maintain balance was declined with age.

Additionally, it has been shown that muscle fatigue could affect the impairment of postural control[12] and muscle fatigue of the lower extremity may affect proprioceptive and kinesthetic of joint by changing joint awareness, perturbing afferent feedback, and also altering the threshold of muscle spindle. These changes, then, can contribute to the deficits in controlling postural stability[13-14]. Forestier *et al.* (2002) reported that fatigue of tibialis anterior and gastrocnemius muscles can lead to an impairment of proprioceptive at ankle joint in young adults[15]. In addition to, Gribble *et al*. (2004) showed that the changes of COP in sagittal plane during unilateral stance was observed after hip, knee, or ankle joint fatigue[16]. In the older adults, a lower capability to perform the lower-extremity reach test and single-limb stance time test was observed after inducing acute knee and ankle fatigue[14]. Moreover, Nam *et al.* (2013) reported that COP length and area of COP during single leg standing were increased after ankle fatigue[17]. Overall, these findings indicate the influences of muscle fatigue on balance and postural stability especially in the older adults.

Several studies investigated the effects of ankle muscles fatigue on postural control in young adults[13, 15-16, 18] but there are only few studies that investigated the effect of ankle fatigue on postural control in the older adults[14, 17] and none has examined postural stability during perturbation after fatigue. Unilateral muscle fatigue is mimic asymmetry of strength and reduced ankle dorsiflexion strength has been shown to predict falls[19-20]. Moreover, it is important to understand the effect of unilateral fatigue on their bilateral postural control in older adult since falls are associated with the ankle asymmetry[19]. Therefore, the aim of present study was to investigate the effect of unilateral ankle muscle fatigue on postural stability; the COP excursion and COM displacement, during perturbation. We hypothesized that unilateral fatigue would affect COP excursion and

COM displacement. Information gained from the present study will be beneficial for developing strength and balance training programs specifically for the elderly.

METHODS

Subjects

Fourteen sedentary older adults (male = 7, female = 7) volunteered to participate in this study. To calculate sample size, effect size was calculated using by G*Power program 3.1.2. Mean and standard deviation of COP excursion form previous study were applied [13]. Power (1- β) and α-level were set at 0.9 and 0.05, respectively. Therefore, the sample size was equaled to 14 after adding 10% drop out. All subjects (aged 65 ± 4 years) was sedentary according to Physical Activity Scale for the Elderly[21] and had score in Berg balance scale and Barthel scale equal or more than 46[22] and 100[23], respectively. Subject were excluded if they had 1) current peripheral neurological deficits, neuropathy, musculoskeletal disorder at lower extremity (LE), and vestibulopathy, 2) experienced about pathological of LE musculoskeletal system in the past year, 3) visual impairment that cannot be corrected with eyeglasses, and 4) taking medicine that affects balance such as Antihistamine, Sedatives, and Anticholinergic. The written informed consent form was signed after the subject has an understanding of the experimental protocol and its risks before participating in the research.

Instrumentation

Three dimensions analysis system including, ten cameras motion capture (BTS DX 5000, BTS Bioengineering, Italy) and force platform (Kistler Instrument AG, Switzerland) were used to collect biomechanics data. Kinematics data were captured at frequency of 200 frames per second, meanwhile, kinetic data sampling rate was collected at 1,600 Hz.[9]. These two devices were synchronized during data collection. For the motion capture, 36 retroreflective markers were used to build the full body model and combine with Rab and Plug-In Gait model[24-25]. SMART Tracker software (BTS SMART DX 5000, BTS Bioengineering, Italy) was used to track data. COM and COP excursion were calculated and biomechanics model was created using Visual3D software (C-motion, Germantown, MD, USA).

Experiment procedure

The Berg balance scale, and Barthel index were used to screen the activities of daily living (ADL) and risk of fall, respectively. Joint position sense was tested using isokinetic dynamometer. The test began with participants moving ankle joint to 30° of plantar flexion (target angle) and maintain that position for 5 seconds. Next, they actively moved ankle joint toward a target angle for 3 repetitions (by themselves) followed by passive movement (machine assisted). Joint positions were set for hip knee and ankle at 90°, 35°, and 80°, respectively. Prior to the perturbation test, participants were familiarized to the test by standing on force platform, raised both arms as quickly as possible to the horizontal, and hold for 2-3 sec, when sound or vision cue was presented and, then, return to the resting position. After that, full body retro-reflexive markers were placed on the participant's body and 15 repetitions of perturbation was started.

Fatigue protocol

Prior performing unilateral ankle fatigue protocol in the dominant leg, maximum voluntary isometric contractions (MVIC) of both dorsi and plantar flexion (MVIC1) were evaluated. Then, ankle exercise was performed with velocity set at 120°/sec (30 repetitions of 3 sets x and 30 seconds rest between set). Once the exercise was completed, the MVIC was tested again immediately to ensure the fatigue was successfully induced (MVIC2 $\leq$ 50). The position of individual participant was set with hip knee and ankle joint at 90°, 35°, and 80°, respectively[26]. After fatigue test, they were asked to perform perturbation test again (within 1-3 min).

Statistical Analysis

All data were analyzed using a PASW Statistics 18.0 (SPSS Inc., Chicago IL, USA). Continuous data were reported as mean ± standard deviation (SD). Categorical data were reported as number and percentage. Shapiro-Wilk test was used to determine the normal distribution of continuous data. Paired T-test was used to test center of pressure and center of mass between pre- and post-fatigue. The level of statistical significant was set at the $p < 0.05$.

RESULTS

General characteristics

Fourteen older adults (7 males and 7 females) aged 65 ± 4 years voluntarily participated in this study. All participants were clearly explained about experimental procedures before providing written inform consent. The study was approved by The Ethics Committee for Human Research at Mahidol University (MU-CIRB 2017/241.2612). General characteristics of the participants are shown in Table 1. Berg balance scale, Barthel index had score 55 ± 1 and 100 ± 0, respectively, and Physical Activity Scale for the Elderly had 98 ± 39 points. For proprioception test, participant took error of active and passive ankle joint position senses to approximate at 4.71 ± 2.69 and 5.93 ± 2.98 degree, respectively.

Table 1 General characteristics of the participants.

Variables	Mean ± SD
Age (years)	65 ± 4
Height (cm)	159.3 ± 10.8
Weight (kg)	61.49 ± 9.24
Error of active ankle joint position sense (°)	4.71 ± 2.69
Error of passive ankle joint position sense (°)	5.93 ± 2.98
Berg balance scale	55 ± 1
Barthel index of activities of daily living	100 ± 0
Physical Activity Scale for the Elderly	98 ± 39

Data are presented as mean±standard deviation.

Center of pressure and center of mass

COP excursion and COM displacement were analyzed during perturbation and compared between pre-fatigue and post- fatigue. It was found that COP excursion in anterior-posterior direction was significantly increased after ankle fatigue ($p<0.05$). However, there was no significant in medial-lateral direction (Table 2). In addition to, significant increase of COM displacement during perturbation after ankle fatigue in anterior-posterior direction ($p<0.05$) was observed with no significant change in medial-lateral direction (Table 3).

Table 2 COP excursion during perturbation between pre-fatigue and post-fatigue conditions.

Direction	Pre-fatigue	Post fatigue
Anterior-Posterior (mm)	20.02 ± 6.41	22.22 ± 6.63*
Medial-Lateral (mm)	11.67 ± 3.25	11.61 ± 2.53

Data are presented as a mean±standard deviation.

* Significantly different between pre-fatigue and post-fatigue (p<0.05).

Table 3 COM displacement during perturbation between pre-fatigue and post-fatigue conditions.

Direction	Pre-fatigue	Post fatigue
Anterior-Posterior (mm)	7.76 ± 1.58	8.80 ± 1.48*
Medial-Lateral (mm)	3.03 ± 0.76	3.10 ± 0.92

Data are presented as a mean±standard deviation.

* Significantly different between pre-fatigue and post-fatigue (p<0.05).

DISCUSSION

All participants passed the cut off score of Physical Activity Scale for the Elderly, Berg balance test, and Barthel index of activities of daily living for include participants[21-23]. These indicate that participants who have been selected in this study were a sedentary group, which can control postural stability and take care of themselves independently in daily life. Moreover, Error of active and passive ankle in dorsi and plantar flexion during proprioception test was classify a normal group[27].

From the present study, acute ankle muscle fatigue of dominant leg in the older adults has modulated postural control during perturbation by an increase of COP excursion and COM displacement in anterior posterior direction. Nevertheless, there was no significant difference in medial-lateral direction when ankle fatigue during perturbation in both COP excursion and COM displacement.

This is in accordance with roles of the ankle movement that control anterior-posterior sway, while hip movement in frontal plane essentially controls medial-lateral movement[28]. Previous study reported COP displacement during perturbation in anterior-posterior direction after ankle fatigue was larger than non-fatigue condition in younger adults[18]. Moreover, COP excursion was larger during bipedal quite standing after ankle fatigue[13]. Therefore, an increase of COP excursion in this study represented postural instability which was influenced by ankle fatigue. It has been suggested that muscle fatigue may alter the function of proprioception system[14-15]. Previous study reported that the activity of muscle spindles, which receives changes of muscle length during movement and plays an important role in stabilization, was decreased after muscle fatigue[6]. Under ischemia, electrically induced fatigue, and local acidosis could lead to disturbances of the input afferent pathway[13, 15]. Therefore, the efferent target e.g. lower extremities muscles that control body movements would need to be compensated in response to the changes of input following fatigue[13].

Several studies have reported relationship between COP and COM relating to postural control[10, 29-30]. COP is center of distribution of the total force applied to the supporting surface, whereas COM is point of the total body mass in global reference system and is the weight average from COM of each body segment in 3D space[29]. Brenière (1996) showed relationship between COP and COM, and mathematical equation model for estimating COM using COP values measured by force platform[30]. Moreover, Tanaka *et al.* (1997) reported a significant positive relationship between lumbar position and COP in anterior-posterior and left sway[10]. Since, one segment may be not inadequate to identify the change of COM displacement, calculation of COM from whole body segment in order to indicate the COM position and postural stability, is an alternative method. Therefore, whole body segment was analyzed in order to precisely represent the COM position in present study.

Madigan *et al.* (2006) reported that COM displacement during lumbar fatigue was increased in anterior posterior direction as well as increased lower extremity joint angle at hip and back[31]. Increases of ankle and hip joint movements after ankle plantar flexor fatigue have also been reported[32]. These likely indicate that fatigue influence a greater lower extremity joint movement in order to maintain posture or recovery balance[33].

CONCLUSION

The results suggest that unilateral ankle muscle fatigue can compromise the postural stability and may increase risk of fall in the older adults representing by increased COP excursion and COM displacement. Therefore, prescribing resistance exercise and balance training to improve ankle muscles strength, endurance and postural control are important for the older adults.

LIMITATION AND FUTURE STUDY

Despite this study found that unilateral muscle fatigue can affect postural instability during perturbation with bipedal standing, the data collection using one force platform may not be able to fully explain the changes of how the contralateral site help compensating to maintain balance during perturbation. Using two force platforms for fatigue and non-fatigue leg may be interesting and further studies are warranted.

REFERENCES

1. Kim MJ, Kim TY, Choi YA, et al. A study on the characteristics of standing posture of elderly women with sarcopenia in Korea. J Exerc Rehabil. 2018;14(3):481.
2. Onambele GL, Narici MV, Maganaris CN. Calf muscle-tendon properties and postural balance in old age. J Appl Physiol. 2006;100(6):2048-56.
3. Granacher U, Zahner L, Gollhofer A. Strength, power, and postural control in seniors: Considerations for functional adaptations and for fall prevention. Eur J Sport Sci. 2008;8(6):325-40.
4. Nagy E, Feher-Kiss A, Barnai M, et al. Postural control in elderly subjects participating in balance training. Eur J Appl Physiol. 2007;100(1):97-104.
5. Lephart SM, Buz Swanik C, Boonriong T. Anatomy and physiology of proprioception and neuromuscular control. Athl Ther Today. 1998;3(5):6-9.
6. Hiemstra LA, Lo IK, Fowler PJ. Effect of fatigue on knee proprioception: implications for dynamic stabilization. J Orthop Sports Phys Ther. 2001;31(10):598-605.
7. Horak FB, Henry SM, Shumway-Cook A. Postural perturbations: new insights for treatment of balance disorders. Phys Ther. 1997;77(5):517-33.
8. Lemay JF, Gagnon DH, Nadeau S, et al. Center-of-pressure total trajectory length is a complementary measure to maximum excursion to better differentiate multidirectional standing limits of stability between individuals with incomplete spinal cord injury and able-bodied individuals. J Neuroeng Rehabil 2014;11(1):8.
9. Kanekar N, Aruin AS. The effect of aging on anticipatory postural control. Exp Brain Res. 2014;232(4):1127-36.
10. Tanaka T, Takeda H, Izumi T, Ino S, Ifukube T. Age-Related Changes in Postural Control Associated with Location of the Center of Gravity and Foot Pressure. Phys Occup Ther Geriatr. 1997;15(2):1-14.
11. Yu E, Abe M, Masani K, Kawashima N, Eto F, Haga N, et al. Evaluation of postural control in quiet standing using center of mass acceleration: comparison among the young, the elderly, and people with stroke. Arch Phys Med Rehabil. 2008;89(6):1133-9.
12. Stackhouse SK, Stevens JE, Lee SC, et al. Maximum voluntary activation in nonfatigued and fatigued muscle of young and elderly individuals. Phys Ther. 2001;81(5):1102-9.
13. Gimmon Y, Riemer R, Oddsson L, Melzer I. The effect of plantar flexor muscle fatigue on postural control. J Electromyogr Kinesiol. 2011;21(6):922-8.
14. Bellew JW, Fenter PC. Control of balance differs after knee or ankle fatigue in older women. Arch Phys Med Rehabil. 2006;87(11):1486-9.

15. Forestier N, Teasdale N, Nougier V. Alteration of the position sense at the ankle induced by muscular fatigue in humans. Med Sci Sports Exerc. 2002;34(1):117-22.
16. Gribble PA, Hertel J. Effect of lower-extremity muscle fatigue on postural control. Arch Phys Med Rehabil. 2004;85(4):589-92.
17. Nam HS, Park DS, Kim DH, et al. The relationship between muscle fatigue and balance in the elderly. Ann Rehabil Med. 2013;37(3):389.
18. Kennedy A, Guevel A, Sveistrup H. Impact of ankle muscle fatigue and recovery on the anticipatory postural adjustments to externally initiated perturbations in dynamic postural control. Exp Brain Res. 2012;223(4):553-62.
19. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age Ageing. 2002;31(2):119-25.
20. Maki BE. Gait changes in older adults: predictors of falls or indicators of fear? J Am Geriatr Soc. 1997;45(3):313-20.
21. Washburn RA, McAuley E, Katula J, Mihalko SL, et al. The physical activity scale for the elderly (PASE): evidence for validity. J Clin Epidemiol. 1999;52(7):643-51.
22. Lajoie Y, Gallagher SP. Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. Arch Gerontol Geriatr. 2004;38(1):11-26.
23. Laohaprasitiporn P, Jarusriwanna A, Unnanuntana A. Validity and reliability of the Thai version of the Barthel Index for elderly patients with femoral neck fracture. J Med Assoc Thai. 2017;100(5): 539-48.
24. Rab G, Petuskey K, Bagley A. A method for determination of upper extremity kinematics. Gait Posture. 2002;15(2):113–9.
25. Davis RB, Õunpuu S, Tyburski D, et al. A gait analysis data collection and reduction technique. Hum Mov Sci. 1991;10(5):575-87.
26. Bisson EJ, McEwen D, Lajoie Y, et al. Effects of ankle and hip muscle fatigue on postural sway and attentional demands during unipedal stance. Gait Posture. 2011;33(1):83-7.
27. Heit EJ, Lephart SM, Rozzi SL. The effect of ankle bracing and taping on joint position sense in the stable ankle. J Sport Rehabil. 1996;5(3):206-13.
28. Winter DA, Prince F, Frank JS, et al. Unified theory regarding A/P and M/L balance in quiet stance. J Neurophysiol. 1996;75(6):2334-43.
29. Winter DA. Human balance and posture control during standing and walking. Gait Posture. 1995;3(4):193–214.
30. Brenière, Y. Why we walk the way we do. J Mot Behav. 1996;28(4):291-8.

31. Madigan ML, Davidson BS, Nussbaum MA. Postural sway and joint kinematics during quiet standing are affected by lumbar extensor fatigue. Hum Mov Sci. 2006;25(6):788-99.
32. Boyas S, Remaud A, Bisson EJ, Cadieux S, Morel B, Bilodeau M. Impairment in postural control is greater when ankle plantarflexors and dorsiflexors are fatigued simultaneously than when fatigued separately. Gait Posture. 2011;34(2): 254-9.
33. Lundin TM, Feuerbach JW, Grabiner MD. Effect of plantar flexor and dorsiflexor fatigue on unilateral postural control. J Appl Biomech.1993;9(3):191- 201.