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Original Paper

Immediate Effects of Plantar Proprioceptive Stimulation on Unipedal Static Postural Stability: A Pilot Study in Healthy Young Adults

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Abstract

Plantar proprioceptive function, often impaired in older patients resulting in poor balance, may be improved by plantar sole stimulation. This study evaluated the immediate effects of such stimulation on single-leg stance in younger adults. Eleven healthy participants, all aged 21, underwent five minutes of plantar sole stimulation. Before and immediately after the stimulation, center of pressure (COP) measurements, including total path length, were taken while participants maintained the single leg standing position with their eyes open. They were instructed to minimize body sway during the assessment. The results showed a significant decrease in the total length of the COP path after stimulation, indicating an improvement in static balance and increased proprioceptive information input. This finding suggests that plantar sole stimulation could effectively improve single-leg static balance in healthy young adults.

1. Introduction

Falls are a common event associated with limitations in activity and participation[1)], underscoring the necessity of implementing fall-prevention programs for older patients. These patients predominantly rely on visual information to maintain postural balance[2)]. This compensatory strategy involves sensory re-weighting among visual, vestibular, and proprioceptive inputs within the central nervous system (CNS)[3)]. In this strategy, the nervous system prefers reliable sensory information from one system over less reliable information from others, following a continuous and dynamic weighting process.

The plantar sole contributes proprioceptive information to the CNS, which comes from plantar receptors, neuromuscular spindles, and skin elements[4)]. This plantar-driven proprioceptive input is crucial for maintaining static postural balance[5)]. Consequently, patients tend to rely more on visual rather than proprioceptive information compared to control participants, which impairs their balance. This impairment has been identified as a contributing risk factor for falls[6)]. Hence, therapeutic interventions to re-weight proprioceptive information could benefit static balance control and fall prevention[6)]. This suggests that plantar sole stimulation could increase reliance on proprioceptive information for basic postural control and improved static balance.

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Previous studies have measured standing balance in a bilateral stance[5], but the effects of interventions on the more challenging static balance in a single-leg stance have not been investigated. Although many studies have utilized bilateral stances for postural balance assessment[7], the single-leg stance offers a more functional and challenging task, potentially better at discriminating between individuals with varying levels of stability. A single-leg balance training protocol has effectively improved balance in healthy adults[8].

Despite these advantages, to our knowledge, no research has yet investigated the impact of plantar sole stimulation on single-leg stance in healthy participants. We hypothesized that plantar stimulation would reduce body sway. Therefore, we analyzed sway during one-legged standing using a force plate, performing a before-and-after comparison.

2. Methods

2. 1. Participants

Eleven healthy participants (five males and six females), with a mean age of 21 years, participated in the study. Their mean body mass was 50.7 ± 6.5 kg, and their mean height was 157 ± 7.4 cm. Exclusion criteria included cardiovascular, respiratory, abdominal, urinary, gynecological, neurological, musculoskeletal, or other chronic diseases. The participants were selected from students at Kawasaki University of Medical Welfare. They voluntarily agreed to participate and provided written informed consent prior to enrollment.

2. 2. Procedures

The intervention consisted of plantar stimulation for all participants. Plantar vibration stimulation (vibration platform; Takatori, Nara, Japan) was administered by a physical therapist using a vibration device at 40 Hz and an amplitude of 1.8 mm for 300 seconds—this stimulation aimed to enhance proprioceptive input to the plantar sole[5]. Participants were seated with their hips and knees at 90° flexion with their feet on the stimulator, maintaining the same position throughout the intervention. Static balance was assessed during single-leg standing on a force platform (T.K.K.5810; Takei Inc, Niigata, Japan) before and after the intervention—the platform, equipped with vertical force transducers in the center, sampled data at 100 Hz. Participants were barefoot during the test. The leg used for the single-leg stance was randomly selected using a function in Excel. The balance test was independent of the dominant and non-dominant leg[9,10]. Participants were instructed to stand as stably as possible for 30 seconds, focusing on a mark 2 meters ahead (Figure 1). They were allowed a practice period with three trials on the force platform[9].

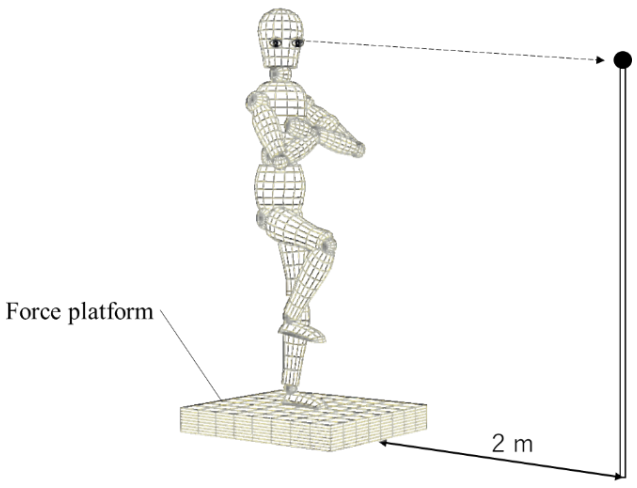

Figure 1 Single-leg stance balance test

In this test, participants maintained a single-leg stance on a force plate. They were instructed to stand as stably as possible, gazing at a mark located 2 meters ahead.

2. 3. Statistical analysis

The total length of the center of pressure (COP) path was calculated as the sum of distances between consecutive points on the COP path, indicating postural stability. These COP displacements reflect an unsteady balance[9]. Statistical analysis was performed using an Excel (Microsoft, Redmond, WA, USA) statistical software package (Social Survey Research Information Co., Ltd., Tokyo, Japan). Assumptions of normality and equality of variances using skewness statistics and histograms were examined Descriptive statistics are presented as mean and standard error (SE). The Wilcoxon signed-rank test was used to compare mean values pre-and post-intervention. A P-value of < 0.05 was considered statistically significant.

3. Results

All participants successfully completed the intervention and the associated outcome measures. Figure 2 displays COP data both before and after the intervention. There was a significant decrease in COP values in the post-intervention period compared to the pre-intervention period ($p < 0.05$).

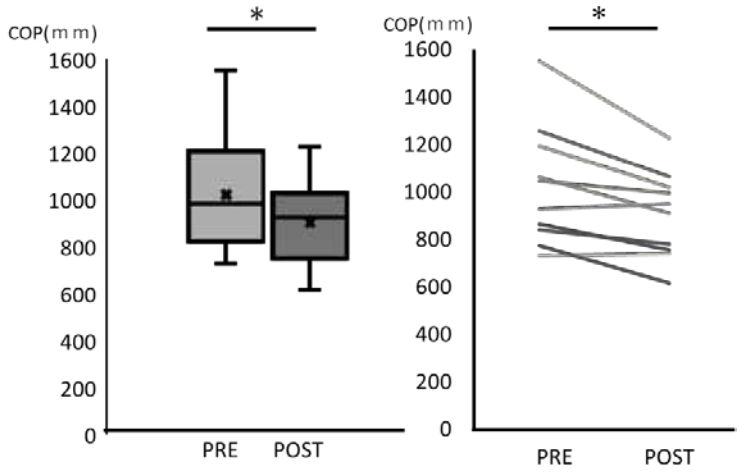

Figure 2 Results of COP analysis between both groups

Lines represent the range between the minimum and maximum. Boxes represent the lower, median, and upper quartiles. *Indicates a significant difference between groups ($p < 0.05$). 'PRE' refers to pre-intervention, and 'POST' refers to post-intervention. The figure includes a boxplot on the left and individual plot data on the right.

4. Discussion

The most notable finding from this study is that plantar sole stimulation altered static postural stability during the single-leg stance task. Generally, a decrease in COP indicates improved balance performance in healthy individuals[8]. The single-leg stance is particularly effective for identifying individuals at risk of falls among older adults[11,12]. Additionally, in both healthy individuals and athletes, instability and pain during the single-leg stance have been associated with decreased strength or impairment in muscles around the hip joint, such as the gluteus medius and minimus[13-15]. Thus, the single-leg stance is a useful indicator for assessing the risk of these conditions.

In this study, participants' COP, as a marker of single-leg stance stability, decreased immediately following plantar sensory input. This reduction suggests that plantar sole sensory input may effectively enhance postural stability. Plantar sole sensory input is beneficial as it increases the sensitivity of cutaneous afferent information from the plantar surface to the CNS[6]. A systematic review by Hijmans et al. supports this, suggesting that vibrating elements on the plantar sole may improve static balance[16]. Presner-Domjan et al.

also proposed that mechanical stimulation of the soles activates plantar mechanoreceptors, compensating for the loss of visual information[17]. Based on these studies, it is hypothesized that the vibration stimulation of the soles induces sensory re-weighting.

However, as this study primarily observed changes in postural sway, the underlying mechanisms, such as sensory re-weighting, remain unclear. Further investigations, including performing the sensory organization test, are necessary to examine variations in sensory contributions. In addition, this study focused only on immediate changes and did not evaluate clinical outcomes such as sustained effects, effects on other aspects of motor function beyond single-leg stance, or duration of effects. Future intervention studies are required to explore these areas.

This study examined the effects of vibration stimulation on balance when applied to the soles of the feet on the balance in single-leg standing in young adults through a pre- and post-intervention comparison. However, one limitation of this study is the absence of a control group. As the current study employed a pre- and post-intervention design without a control group, it is difficult to determine whether the observed reduction in the total trajectory length post-intervention was due to the vibration stimulation itself or a potential learning effect from repeated measurements. Therefore, future studies should consider employing a randomized controlled trial (RCT) with a control group to address these concerns. Additionally, as this study was a pilot study, no formal sample size calculation or considerations were conducted.

These findings suggest that single-leg stance stability in healthy individuals can be improved through plantar sole sensory input. This opens the possibility of using sensory re-weighting to enhance plantar mechanoreceptors and reduce reliance on visual information for dynamic postural control. However, more research is needed to develop clinical applications.

Acknowledgements

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Ethical considerations

The study was approved by the ethics committee of Kawasaki University of Medical Welfare (Permit Number 20-091), Okayama, Japan.

5. References

1. Thomas E, Battaglia G, Patti A, Brusa J, Leonardi V, Palma A and Bellafiore M : Physical activity programs for balance and fall prevention in elderly: A systematic review. *Medicine*, 98(27), e16218, 2019, doi: 10.1097/MD.0000000000016218.
2. Lord SR and Menz HB : Visual contributions to postural stability in older adults. *Gerontology*, 46(6), 306-310, 2000.
3. Mahboobin A, Loughlin P, Atkeson C and Redfern M : A mechanism for sensory re-weighting in postural control. *Medical and Biological Engineering and Computing*, 47, 921-929, 2009.
4. Roll R, Kavounoudias A and Roll JP : Cutaneous afferents from human plantar sole contribute to body posture awareness. *Neuroreport*, 13(15), 1957-1961, 2002.
5. Oku K, Kawahara I, Sugioka T, Tanaka Y, Hoshiba T, Hirose N and Kumai k : Immediate effects of plantar vibration stimuli during static upright posture following total hip arthroplasty in females. *Somatosensory and Motor Research*, 37(4), 238-244, 2020.
6. Park JH : The effects of plantar perception training on balance and falls efficacy of the elderly with a history of falls: Asingle-blind, randomized controlled trial. *Archives of Gerontology and Geriatrics*, 77, 19-23, 2018.
7. Michikawa T, Nishiwaki Y, Takebayashi T and Toyama Y : One-leg standing test for elderly populations. *Journal of Orthopaedic Science*. 14(5), 675-685, 2009.

8. Marcori AJ, Monteiro PH, Oliveira JA, Doumas MD and Teixeira LA : Single leg balance training: A systematic review. *Perceptual and Motor Skills*, 129(2), 232-252, 2022.
9. Da Silva RA, Bilodeau M, Parreira RB, Teixeira DC and Amorim CF : Age-related differences in time-limit performance and force platform-based balance measures during one-leg stance. *Journal of Electromyography and Kinesiology*, 23(3), 634-639, 2013.
10. Muehlbauer T, Mettler C, Roth R and Granacher U : One-leg standing performance and muscle activity: are there limb differences? *Journal of Applied Biomechanics*, 30(3), 407-414, 2014.
11. Seichi A, Hoshino Y, Doi T, Akai M, Tobimatsu Y, Kita K and Iwaya T : Determination of the optimal cutoff time to use when screening elderly people for locomotive syndrome using the one-leg standing test (with eyes open). *Journal of Orthopaedic Science*, 19(4), 620-626, 2014.
12. Khanal P, He L, Stebbings GK, Onambele-Pearson GL, Degens H, Williams AG, Thomis M and Morse CI : Static one-leg standing balance test as a screening tool for low muscle mass in healthy elderly women. *Aging Clinical and Experimental Research*, 33, 1831-1839, 2021.
13. Lequesne M, Mathieu P, Vuillemin-Bodaghi V, Bard H and Djian P : Gluteal tendinopathy in refractory greater trochanter pain syndrome: diagnostic value of two clinical tests. *Arthritis Care and Research*, 59(2), 241-246, 2008.
14. Youdas JW, Mraz ST, Norstad BJ, Schinke JJ and Hollman JH : Determining meaningful changes in pelvic-on-femoral position during the Trendelenburg test. *Journal of Sport Rehabilitation*, 16(4), 326-335, 2007.
15. Kivlan BR and Martin RL : Functional performance testing of the hip in athletes: A systematic review for reliability and validity. *International Journal of Sports Physical Therapy*, 7(4), 402-12, 2012.
16. Hijmans JM, Geertzen JH, Dijkstra PU and Postema K : A systematic review of the effects of shoes and other ankle or foot appliances on balance in older people and people with peripheral nervous system disorders. *Gait and Posture*, 25(2), 316-323, 2007.
17. Preszner-Domjan A, Nagy E, Szíver E, Feher-Kiss A, Horvath G and Kranicz J : When does mechanical plantar stimulation promote sensory re-weighing: Sanding on a firm or compliant surface? *European Journal of Applied Physiology*, 112(8), 2979-2987, 2012.