

Determining the optimal frequency and current intensity of microcurrent stimulation for postural sway induction: A pilot study

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ABSTRACT

Background: Maintaining postural balance is crucial for various daily activities, and the vestibular system plays a significant role in this process. Dysfunction in the vestibular system can result in impaired postural control and balance. Microcurrent therapy, which uses lower current intensities than traditional electrical stimulation methods, may offer a less painful alternative for vestibular system training.

Objective: This pilot study aimed to investigate the effects of microcurrent stimulation on vestibular system training for posture control, with an emphasis on sway velocity and muscle activity, and to determine its optimal frequency and electric current intensity.

Materials and methods: Twenty healthy young adults (mean age, 22.35 years; 76.5% female; mean body mass index, 24.5 ± 3.5 kg/m²) participated in this study. Surface electromyography (EMG) of the tibialis anterior muscle and postural sway were measured during microcurrent stimulation at varying frequencies (0.5 Hz to 2.0 Hz) and intensities (50 μ A to 400 μ A) on the bilateral mastoid processes of 15 seconds each. The center of pressure displacement was recorded using a pressure platform, and muscle activity was assessed through EMG data.

Results: The results showed that frequency did not significantly affect postural sway or muscle activity, whereas intensity did. Muscle activity was greatest at 1.5 Hz and 400 μ A, and postural sway was most pronounced at 2.0 Hz and 400 μ A. No adverse reactions were reported during or after the stimulation sessions.

Conclusion: Microcurrent stimulation with optimal current and intensity may be a useful, non-invasive option for vestibular system training, particularly in populations where traditional electrical stimulation may cause discomfort. Further studies involving older adults and individuals with vestibular dysfunction are necessary to validate these findings.

Introduction

To maintain one's balance, the human body's center of gravity should fall within the weight support center of mass, for which continuous adjustment is required from the positioning of joints and muscle activity.¹ Sustaining standing balance is among the most important functions of the human body in various activities of daily living.² The central nervous system (CNS) controls one's postural balance through the vestibular, visual, and proprioceptive systems,^{3,4} as well as the motor system of the human body.^{1,2,5} Among the three systems, the vestibular system is the most unique because it is instantly multisensory and multimodal. For instance, it works with proprioception and

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corollary discharge of the motor system/plan, enabling the cortex to differentiate activities caused by passive head movements.⁶ During various movements of the head and body, the vestibular system maintains stability.^{4,7} The peripheral vestibular system detects physical stimuli, such as head rotation, acceleration, and gravity, and converts them to electrical signals for transmission to the CNS.⁸ The CNS uses information from the vestibular system to determine the head's position and speed, integrates it with information from the proprioceptive and visual systems, and maintains the body's posture and balance.⁸

Vestibular system dysfunction has gained clinical recognition as an important differential diagnosis for decreased postural control. People with balance disorders, vestibular system defects, or both tend to abstain from physical activity and social gatherings to avoid unexpected falls, which affect their quality of life.⁹ Vestibular system training was developed to gradually increase eye, head, and body movements to stimulate the vestibular system and promote the CNS to adapt to new information.¹⁰ This training can reduce the fear of dizziness during daily activities and enhance the balance sensation, making it ideal for patients with peripheral vestibular dysfunction.¹⁰ Four types of vestibular training are available: adaptation, habituation, substitution, and balance exercise.¹¹ The recovery of vestibular function mainly relies on CNS plasticity, and natural recovery, adaptation, and substitution can promote recovery through these mechanisms.

Additionally, the approach widely used to improve postural control involves inducing perturbations and enhancing the effects of balance training by repeating the process of recovery using motor learning through repetition and adaptation.^{12,13} It is possible that postural sway caused by electrical stimulation could serve as a form of balance training, as the individual would need to use their muscles to destabilize the stimulation and maintain their balance.¹⁴ This is similar to other forms of balance training such as standing on a wobble board or performing exercises on an unstable surface. However, the effectiveness of this training type may depend on several factors, such as the frequency and intensity of electrical stimulation. In addition, it is important to ensure that electrical stimulation during training is safe and does not pose a risk of injury.

Microcurrent stimulation has been hypothesized to enhance neural activity through mechanisms such as increased ATP production, which supports cellular energy metabolism and facilitates neural adaptation.¹⁵ Additionally, microcurrent has been reported to improve blood flow and tissue repair, which may aid in rehabilitative processes involving the vestibular system.¹⁶ On a neural level, electrical stimulation, including microcurrent, has the potential to enhance synaptic plasticity, a critical factor in the central nervous system's ability to adapt to balance perturbations.¹⁷ These mechanisms highlight its potential as a therapeutic tool for vestibular system rehabilitation.

Sinusoidal or galvanic currents have been used as direct electrical stimulation methods for the vestibular systems to improve postural control. Such currents are applied to the mastoid process to stimulate the vestibular nerve directly;¹⁸ however, most patients complain of unpleasant pain due to strong electrical currents.¹⁹ Previous studies have demonstrated the potential of vestibular stimulation to improve postural sway and muscle activation in different age groups, highlighting its utility in balance control interventions.²⁰ Despite this, the discomfort associated with galvanic stimulation often limits its clinical application, especially for individuals with heightened pain sensitivity. In contrast, microcurrent therapy stimulates muscle contraction without discomfort or pain by using a microampere (μ A) rather than milliampere (mA) current.²¹ Research has shown that microcurrent stimulation can improve balance performance in the 100-300 μ A,²² suggesting its potential to painlessly stimulate the vestibular system. Furthermore, microcurrents have been reported to alleviate muscle symptoms, supporting their use in clinical rehabilitation.^{16,23}

Direct current galvanic stimulation has been shown to effectively stimulate the vestibular system but is often accompanied by discomfort and pain, limiting its clinical application.²⁴ To address this limitation, this study explored the use of microcurrent stimulation, which delivers significantly lower intensities, as an alternative method for vestibular stimulation. However, the optimal intensity of microcurrent stimulation for effective vestibular activation remains unclear. Therefore, this study systematically varied microcurrent intensity (50 μ A to 400 μ A) and frequency (0.5 Hz to 2.0 Hz) to identify parameters that could maximize the effects on postural control while minimizing discomfort.

The primary objective was to determine the most effective microcurrent intensity for stimulating the vestibular system, with the potential to develop a safer and more tolerable intervention for clinical rehabilitation.

Materials and methods

Ethical approval

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Institutional Review Board of Eulji University (EU19-68). All participants signed an informed consent form before starting the experiment. The manuscript was prepared in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

Participants

Twenty healthy young adults aged ≥ 18 years with no problem receiving microcurrent stimulation to the vestibular system volunteered to participate. Three participants were excluded because they did not meet the inclusion criteria. The participants were excluded if they had a history of recent lower-extremity injury or disability, visual or neurological deficits, cardiopulmonary diseases, or mental problems. We also excluded subjects

if their one-leg standing test time was <27.5 sec, the mean of young healthy adults aged 20-30 years to prevent falls during the balance tasks. We also excluded those who showed an unpleasant reaction to electrical stimulation during the screening process.

Procedure

When the participants arrived at the laboratory, their general anthropometric characteristics such as height, weight, and body mass index were obtained. Next, electromyography (EMG) signals of the tibialis anterior (TA) muscle and postural sway were recorded on the pressure platform while the subjects received various microcurrent stimulations on the bilateral mastoid processes for 15 s each. To minimize head movement, participants were instructed to stare at the "+" sign at eye level on the wall and maintain a standing posture.

Outcome measurements

Measurement of postural control (or center of pressure)

A Zebis FDM-S pressure platform (Zebis Medical GmbH, Isny im Allgau, Germany) was used to assess center of pressure (CoP) displacement. The pressure platform-calibrated capacitive force sensors underneath the platform at a sampling rate of 60 Hz enable the assessment of the distribution of static forces. MR 3.8 software (Noraxon Inc., Scottsdale, AZ, USA) was used to integrate the force signals and graphic representation of the CoP. The area of the CoP path (mm²), length of the CoP path (mm), and sway velocity (mm/s), defined as the mean CoP movement speed, were used to determine postural sway. The participants were instructed to maintain their standing posture on a pressure platform during various microcurrent stimulations.

Measurement of muscle activity on EMG

A wireless surface Trigno EMG sensor (DELSYS, Natick, MA, USA) was used at a sampling rate of 2000 Hz to measure the muscle activity. Prior to the EMG measurement, the skin was shaved and wiped with alcohol to reduce impedance. Disposable pre-gelled bipolar Ag/AgCl surface electrodes were placed over the muscle belly parallel to the muscle fibers. The electrodes were placed on the muscle belly of the TA of both legs. Surface EMG electrodes were secured with a bandwidth set between 10 Hz and 350 Hz, and the notch filter was set at 60 Hz to minimize noise distortion. The signal of each muscle was normalized to the reference maximal voluntary isometric contraction (MVIC). The participants were seated on chairs, and maximum dorsiflexion forces were measured against the exertional force toward the floor on the participant's ankle during lifting to measure the MVIC of the TA muscle. MVIC measurements were taken three times with a 1-min rest period between contractions, and the average middle 3 s of the MVIC was analyzed.²⁵

The TA muscle was selected for its key role in maintaining postural balance during anterior-posterior sway, which is commonly induced by vestibular stimulation. Previous studies have highlighted the involvement of the TA, soleus, and gastrocnemius muscles in stabilizing postural sway.¹⁶ The TA muscle, in particular, is essential for controlling dorsiflexion and anterior stability, making it a suitable indicator of balance control.²⁶ Future research could include other muscle groups, such as the soleus and gastrocnemius, to provide a broader understanding of balance mechanisms.

EMG data of the TA were collected for 15 s while participants were standing on the pressure platform during microcurrent stimulation of the vestibular system at varying frequencies and current intensities, but only for 10 s. The root mean square value was used to quantify the electric signal of the amplitude of the EMG signal for a given period because it estimates the muscular exertion intensity.^{27,28}

Microcurrent electrical stimulation

Microcurrent electrical stimulation was performed using an Acutron Mentor (Eastwestmed, Inc., Phoenix, AZ, USA), with HRTC 32AP stimus hydrogel electrodes were placed on the mastoid process.

The range of 50–400 microamperes (μA) for current intensity was selected based on a combination of prior research and preliminary testing. Previous studies using galvanic vestibular stimulation (GVS) to stimulate the vestibular system reported increased postural sway at current intensities of 0.2 mA, 0.5 mA,^{27,28} and 0.7 mA.²⁹ To identify the minimum and maximum microcurrent intensities capable of stimulating the vestibular nerve without causing discomfort, preliminary testing was conducted in this study. The range of 50–400 μA was established as the threshold where participants reported no unpleasant sensations while maintaining sufficient stimulation of the vestibular nerve. Additionally, because this study targeted healthy young adults with intact vestibular and somatosensory systems, it was hypothesized that effective stimulation could be achieved using relatively low microcurrent intensities.

Based on the previous evidence and preliminary testing, microcurrent stimulation began with 0.5 Hz and 50 μA intensity while the participants maintained a standing position. Subsequently, 0.5 Hz and 100 μA, 200 μA, 300 μA, and 400 μA were applied, respectively, with a 15-sec break between experiments. Similarly, frequencies of 1.0 Hz, 1.5 Hz, and 2.0 Hz were applied in combination with current intensities of 50 μA, 100 μA, 200 μA, 300 μA, and 400 μA, respectively. If the participant experienced nausea, a tickling sensation, unbearable pain, or an unpleasant feeling due to electrode attachment during the experiment, the trial was immediately discontinued (Figure 1).

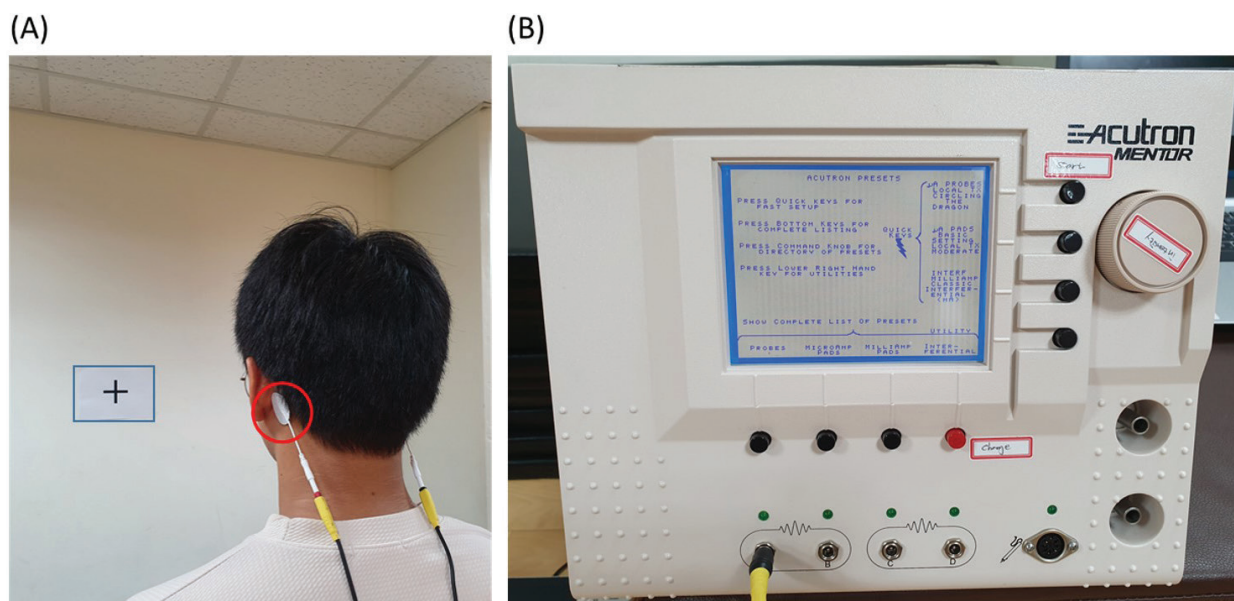


Figure 1. Application of microcurrent stimulation on bilateral mastoid processes.

Statistical analysis

SAS version 9.4 (SAS Institute, Inc. Cary, NC, USA) and R software version 4.0.4 (R Project for Statistical Computing, Vienna, Austria) were used to analyze the data, which were summarized as means and standard deviations (SD) or medians with maximum and minimum. The Shapiro-Wilk test was used to confirm the assumption of normality of the continuous variables. Non-parametric repeat-measures analysis of variance was conducted to test the data. The level of significance was set at $\alpha=0.05$.

Results

None of the participants reported unpleasant symptoms or irritation under the electrodes during or after stimulation trials. Additionally, none of the participants noticed the stimulation applied during the trials. The patients' general characteristics are described in Table 1.

Table 2 and Figure 2 show the TA muscle activity and balance parameters such as CoP area, CoP length, and

CoP velocity. There was no significant interaction between the frequency and intensity postural balance parameters (CoP area, CoP sway length, and CoP sway velocity) and EMG. In addition, muscle activity and postural balance parameters were not statistically significant among the different frequencies ($p>0.05$) but were significantly different among intensities ($p<0.001$). Muscle activity was maximum at a combination of 1.5 Hz and 400 μA and minimal at 2.0 Hz and 50 μA . The CoP area, sway length, and velocity were the greatest at the combination of 2.0 Hz and 400 μA , while CoP area was the lowest at 0.5 Hz and 50 μA , while CoP length and velocity were the lowest at 1.5 Hz 50 μA .

The findings demonstrated a significant increase in muscle activity and postural sway with higher intensity levels, particularly at 300 μA and 400 μA . This trend suggests that intensity serves as a critical determinant of vestibular stimulation effectiveness, likely due to its direct impact on vestibular nerve excitation thresholds.

Table 1. General characteristics of participants (N=20)

Characteristics	
Sex, female [N (%)]	13 (76.5%)
Age (years; mean $\pm$ SD)	22.35 $\pm$ 2.12
Height (cm; mean $\pm$ SD)	171.5 $\pm$ 15.2
Weight (kg; mean $\pm$ SD)	65.2 $\pm$ 10.5
BMI (kg/m ² ; mean $\pm$ SD)	24.5 $\pm$ 3.5

Note: BMI: body mass index, SD: standard deviation.

Table 2. Muscle activity and postural sway at different frequencies and intensities.

Frequency (Hz)	Amplitude (μA)	EMG (%)	p [†]	CoP area (mm ²)	p [†]	CoP sway length (mm)	p [†]	CoP sway velocity (mm/sec)	p [†]
0.5	50	32.5±9.7	0.466	130.0±144.2	0.562	96.3±87.7	0.686	9.5±8.6	0.485
	100	32.5±9.4		139.8±179.9		100.6±80.3		10.0±7.9	
	200	33.1±9.4		157.8±147.2		121.6±111.1		12.0±9.6	
	300	33.5±8.9		161.2±108.8		123.6±96.7		11.9±11.0	
	400	34.1±9.1		202.3±161.2		129.1±134.0		12.7±9.3	
1.0	50	32.6±9.5		137.8±112.5		99.3±73.2		9.6±7.2	
	100	32.8±9.7		141.9±201.3		112.7±94.91		11.1±9.42	
	200	33.1±9.4		162.2±171.9		124.9±137.8		12.1±8.6	
	300	33.2±9.3		170.6±213.4		126.0±121.3		12.3±11.9	
	400	33.9±8.5		209.0±194.5		150.6±190.6		13.7±19.0	
1.5	50	32.3±9.3		133.4±77.8		87.9±71.3		9.4±6.0	
	100	32.4±9.9		136.8±106.6		96.4±60.9		10.8±10.0	
	200	32.6±9.6		158.8±111.9		110.3±102.1		11.5±7.0	
	300	33.0±9.7		180.2±115.9		106.2±97.1		13.5±9.5	
	400	34.1±9.3		207.4±165.6		129.0±135.2		14.8±13.2	
2.0	50	31.3±8.8		136.6±81.2		151.2±107.9		11.8±10.4	
	100	31.7±9.0		143.5±110.3		156.4±121.8		12.4±11.7	
	200	32.1±9.0		163.0±167.8		156.8±99.3		14.4±9.4	
	300	33.5±8.8		188.0±120.1		160.4±108.5		14.9±10.3	
	400	34.0±8.9		212.8±183.5		172.3±154.1		17.0±12.0	

Note: EMG: electromyography, CoP: center of pressure, † Interaction between frequency and intensity.

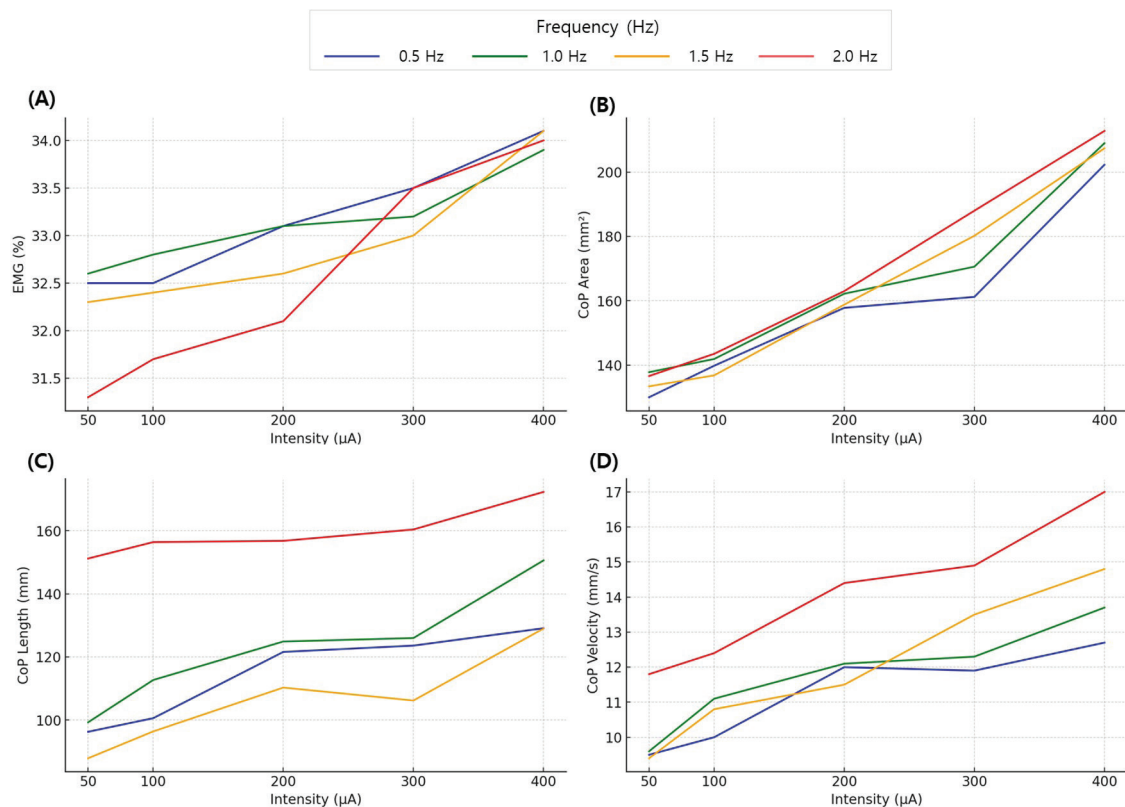


Figure 2. Frequency and Intensity on muscle activity (A), CoP area (B), CoP Length (C), and CoP velocity (D).

Discussion

This pilot study aimed to investigate the effect of microcurrent stimulation on vestibular system training for posture control and determine the optimal frequency and electric current intensity for training. The microcurrent stimulation used in this study involved applying electrical stimulation directly to the mastoid process, which stimulated the vestibular nerve directly without passing through the peripheral vestibular receptors. The resulting sway was recorded using a force plate and EMG without involving the peripheral vestibular receptors. Our results showed that the frequency of microcurrent stimulation did not significantly affect postural sway and muscle activity, whereas intensity did. The lack of significant impact from frequency variations on postural sway and muscle activity could be attributed to the lower sensitivity of the vestibular system to frequency changes compared to intensity. Previous studies suggest that muscle responses and postural adjustments are more closely tied to the magnitude of the stimulation rather than its temporal characteristics.^{30,31} This indicates that intensity plays a more dominant role in eliciting physiological responses during vestibular stimulation. Muscle activity was greatest at a combination of 1.5 Hz and 400 μA, while the postural sway parameters were greatest at a combination of 2.0 Hz and 400 μA, supporting previous evidence that optimal stimulation amplitude for balance improvement is within the range of ± 100 to ± 400 μA.²² Our results also suggest that when individuals with reduced postural balance control are stimulated, TA muscle activity increases along with postural balance parameters.

The findings of this study align with previous research on GVS, demonstrating that increased current intensity induces greater postural sway due to heightened vestibular nerve activation.^{24,29} Similarly, our findings indicate that microcurrent stimulation, despite using significantly lower current levels (1/1000th of GVS intensity), can effectively stimulate the vestibular system. This highlights its potential as a safer and more tolerable alternative for balance training. Compared to GVS, microcurrent stimulation utilizes significantly lower intensities, offering a safer and more tolerable alternative, particularly for healthy individuals and populations with heightened sensitivity.

Galvanic and microcurrent differ in current intensity, but they are both direct currents. Microcurrents can stimulate the vestibular system with minimal stimulation with minimal discomfort.²⁹ This reduced pain or unpleasant sensations increases user satisfaction compared to conventional galvanic stimulators. While galvanic current intensity is often limited by pain, microcurrent stimulation allows greater flexibility in adjusting intensity and frequency, making it beneficial for personalized treatments. This approach is particularly advantageous for elderly individuals with decreased balance ability, where a reduced pain burden lowers the risk of falling and enhances overall safety.

The existing exercise for the vestibular system involves physical stimulation of the hair cells in the peripheral vestibular receptors, which generates electrical signals and triggers the nystagmus reflex.³² However, it is unclear which parts of the peripheral vestibular receptors and vestibular nerves should be targeted. However, in the current study,

electrical stimulation was applied directly to the ampulla, which can create a postural sway or nystagmus response without passing through the peripheral vestibular organs. This type of stimulation may be useful in cases of vestibular nerve problems since it bypasses the nerve and directly stimulates the vestibular end organs. Furthermore, microcurrent stimulation of the vestibular system can lead to exercise-like effects because it initiates a process of self-recovery in which the body repeatedly adjusts and stabilizes itself after each stimulation. This process can strengthen the vestibular system, similar to strengthening the muscles.³³ In addition, a microcurrent stimulator was proven to raise the tissue temperature and generate sedation, decreasing symptomatic pain.³⁴ It also effectively improves muscle function and promotes recovery by enhancing blood flow through the skin;¹⁶ thus, it has been widely used as an effective, easy-to-use, noninvasive, and time-efficient treatment method.

Limitation

This pilot study of healthy adults aimed to determine the most effective frequency and electric current intensity of microcurrent stimulation for training the vestibular system. However, as this is a pilot study, a formal sample size calculation was not performed, and the findings are based on a small sample of 20 participants. While this sample size was sufficient for a preliminary investigation, future studies with larger and more diverse populations are necessary to validate these findings and ensure their generalizability. It is also necessary to test this system in elderly individuals or patients who require vestibular rehabilitation to confirm the appropriateness of its parameters. Additionally, further research combined with various balance training methods is needed, as it might have stronger synergistic effects with balance training. Finally, studies investigating the prolonged effects of microcurrent stimulation over time are required to establish its long-term efficacy and safety.

Conclusion

This pilot study found that the optimal frequency and current intensity for microcurrent vestibular stimulation for improving postural control is 2.0 Hz and 400 μ A for postural sway and 1.5 Hz and 400 μ A for muscle activity. These findings suggest that microcurrent stimulation may be a valuable tool for vestibular system training, particularly in cases of vestibular dysfunction. Its low-intensity, non-invasive nature makes it a more suitable and tolerable option for elderly individuals or those with heightened sensitivity, as it minimizes pain and discomfort. This approach has potential for enhancing balance training and supporting vestibular rehabilitation. Microcurrent stimulation could be tailored for diverse patient populations, but further studies with larger samples and longitudinal designs are needed to validate its efficacy and broader clinical applications.

Ethical approval

The study adhered to the guidelines of the Declaration

of Helsinki and was approved by the Institutional Review Board of Eulji University (EU19-6). Informed consent was obtained from all study subjects.

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Conflicts of Interest

The authors declare no conflicts of interest.

CRediT authorship contribution statement

Conceptualization: WY and HL; **methodology:** WY; **formal analysis:** HL; **investigation:** WY; **data curation:** WY and HL; **writing-original draft preparation:** WY and HL; **writing-review and editing:** WY and HL, **funding acquisition:** WY. All authors have read and agreed to the published version of the manuscript.

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