Vibrotactile Feedback for Gait Rehabilitation

Executive Summary

Walking impairments are a major cause of reduced mobility, falls, and loss of independence in individuals with neurological disorders and age-related mobility decline. As the demand for effective rehabilitation continues to grow, there is increasing interest in technologies that can support gait training beyond the clinical setting.

Wearable vibrotactile feedback is one such approach. By delivering precisely timed tactile cues during walking, these systems augment the sensory information available to the nervous system, supporting gait control and motor learning rather than replacing natural movement. A growing body of research demonstrates that vibration can influence proprioception, enhance sensorimotor processing, and improve clinically relevant aspects of gait [1–4].

This paper reviews the scientific principles underlying wearable vibrotactile feedback, summarizes the current clinical evidence, and discusses how these findings support the development of wearable rehabilitation technologies for improving gait and functional mobility.

1. The Sensorimotor Control of Human Gait

Walking is a highly coordinated activity that depends on the continuous integration of sensory information and motor control. During every step, the nervous system combines input from the visual, vestibular, proprioceptive, and cutaneous systems to maintain balance, adapt to the environment, and produce efficient movement.

Among these sensory systems, proprioception and plantar sensory feedback are particularly important. Proprioceptive receptors provide information about limb position and movement, while mechanoreceptors in the sole of the foot detect pressure distribution, ground contact, and weight transfer throughout the gait cycle. Together, these sensory inputs enable the nervous system to regulate posture, coordinate movement, and adapt walking to changing conditions [1,2,5].

When sensory function is impaired, as commonly observed in Parkinson's disease, stroke, multiple sclerosis, diabetic peripheral neuropathy, and healthy aging, gait often becomes slower, less stable, and more variable, increasing the risk of falls and reducing functional mobility [3,4].

These observations have shifted rehabilitation research beyond strengthening muscles and improving movement mechanics toward approaches that also enhance the sensory information available during walking. This concept forms the foundation for wearable vibrotactile feedback technologies.

2. Scientific Basis of Vibrotactile Feedback

Building on the importance of sensory feedback for gait control, vibrotactile stimulation aims to augment rather than replace the body's natural sensory information. By delivering precisely timed tactile cues, wearable systems provide additional input that can support movement perception and postural control during walking.

The physiological basis for this approach was established by Goodwin et al. [1] and Roll and Vedel [2], who demonstrated that vibration can influence proprioceptive perception by activating muscle spindle afferents. More recently, Visell et al. [6] showed that vibrotactile stimulation can alter sensory perception during walking, while Trotman et al. [4] concluded that plantar stimulation influences neuromuscular responses and gait. Together, these findings demonstrate that vibration can meaningfully interact with the sensorimotor system and provide a scientific rationale for wearable sensory augmentation.

Rather than serving as a substitute for natural sensory function, wearable vibrotactile feedback is designed to reinforce the sensory information available during walking. This principle underpins the development of modern rehabilitation technologies that aim to improve gait through enhanced sensory guidance.

3. Vibrotactile Feedback Supports Motor Learning

Beyond its immediate effects on movement, vibrotactile feedback has the potential to support motor learning, the process through which repeated practice leads to lasting improvements in movement performance.

Research has consistently shown that external feedback plays an important role in learning motor skills. A comprehensive review [7] concluded that visual, auditory, and haptic feedback can enhance motor performance and learning when feedback is meaningful, appropriately timed, and integrated into the task. These findings are consistent with established motor learning principles, which emphasize that well-designed feedback facilitates skill acquisition and movement adaptation [8–10].

Compared with visual or auditory cues, vibrotactile feedback offers several practical advantages during walking. Because tactile cues do not compete for visual or auditory attention, they can provide continuous movement guidance while allowing individuals to remain aware of their surroundings. This makes wearable vibrotactile systems particularly well suited for gait rehabilitation in everyday environments.

By combining sensory augmentation with real-time feedback, wearable vibrotactile technologies have the potential not only to improve walking in the moment but also to reinforce more efficient movement patterns over time.

4. Clinical Evidence Supporting Vibrotactile Feedback

Growing clinical evidence suggests that vibrotactile feedback can improve gait and balance, particularly in individuals with impaired sensorimotor function. Although the optimal stimulation strategies and long-term effects continue to be investigated, systematic reviews and clinical studies consistently support the therapeutic potential of wearable vibrotactile interventions.

Reviews of vibration and plantar sensory stimulation have reported effects on clinically relevant aspects of gait, including gait speed, step length, gait symmetry, and walking stability [3,4]. Layne et al. [3] reported effects of vibration on gait across a range of clinical populations, while the systematic review by Trotman et al. [4] found moderate evidence that enhanced plantar sensory stimulation alters muscle activity during gait.

[3][4]More recent studies have investigated wearable systems that deliver vibrotactile feedback directly through footwear. Hatton et al. [11] demonstrated that vibrating shoe insoles influenced postural control and ankle-foot muscle activity in individuals with diabetic peripheral neuropathy, supporting the concept that sensory feedback delivered through footwear can modify gait-related neuromuscular function.

Encouraging results have also been reported in Parkinson's disease. Cen et al. [12] demonstrated that a wearable vibrotactile foot device reduced freezing of gait and improved walking performance. Similarly, Bowman et al. [13] reported improvements in gait speed, step length, and walking distance using a wearable biofeedback system, while Kirsch et al. [14] demonstrated that real-time vibratory feedback based on stride parameters further improved gait characteristics, supporting the potential of adaptive, closed-loop vibrotactile feedback for gait rehabilitation. Collectively, these studies also demonstrate the feasibility of integrating wearable vibrotactile feedback into rehabilitation and everyday mobility.

Taken together, the available evidence indicates that wearable vibrotactile feedback has the potential to improve gait by enhancing sensory input and supporting motor adaptation.

5. From Scientific Evidence to Wearable Rehabilitation

Collectively, the available evidence supports the use of wearable vibrotactile feedback as a promising adjunct to conventional gait rehabilitation. By enhancing sensory information during walking, wearable systems have the potential to support motor learning and reinforce more effective movement patterns beyond supervised therapy sessions.

Unlike traditional rehabilitation, which is typically confined to clinical environments, wearable technologies allow gait-related feedback to be delivered during everyday activities. This creates opportunities for more frequent practice in real-world settings, where improvements in walking are most meaningful to patients.

Although further clinical studies are needed to optimize intervention strategies and evaluate long-term outcomes, current research provides a strong scientific rationale for integrating wearable vibrotactile feedback into modern rehabilitation programmes.

Conclusion

Advances in neuroscience, rehabilitation, and wearable technology are changing how gait rehabilitation can be delivered. Rather than being limited to supervised therapy sessions, rehabilitation can increasingly be supported during everyday activities through wearable systems that provide meaningful sensory feedback in real time.

The evidence presented in this paper demonstrates that vibrotactile feedback is supported by a growing body of physiological and clinical research. By augmenting natural sensory information, wearable technologies have the potential to support motor learning, improve gait performance, and extend rehabilitation beyond the clinical setting. Although further clinical validation will continue to refine these approaches, wearable vibrotactile systems represent a promising step toward more accessible, continuous, and patient-centered gait rehabilitation.

References

[1] Goodwin GM, Mccloskey DI, Matthews PBC. Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? Science 1972;175:1382–4. https://doi.org/10.1126/SCIENCE.175.4028.1382.

[2] Roll JP, Vedel JP. Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. Exp Brain Res 1982;47:177–90. https://doi.org/10.1007/BF00239377.

[3] Layne CS, Malaya CA, Levine JT. The effects of muscle vibration on gait control: a review. Somatosens Mot Res 2019;36:212–22. https://doi.org/10.1080/08990220.2019.1652585.

[4] Trotman M, Ha PL, Tucker K, Cattagni T, Hatton AL. The effects of plantar surface stimulation on neuromuscular responses during standing balance and gait in healthy and clinical populations: A systematic review. Journal of Electromyography and Kinesiology 2025;82. https://doi.org/10.1016/j.jelekin.2025.103007.

[5] Strzalkowski NDJ, Ali RA, Bent LR. The firing characteristics of foot sole cutaneous mechanoreceptor afferents in response to vibration stimuli. J Neurophysiol 2017;118:1931–42. https://doi.org/10.1152/JN.00647.2016.

[6] Visell Y, Giordano BL, Millet G, Cooperstock JR. Vibration influences haptic perception of surface compliance during walking. PLoS One 2011;6. https://doi.org/10.1371/JOURNAL.PONE.0017697.

[7] Sigrist R, Rauter G, Riener R, Wolf P. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review. Psychon Bull Rev 2013;20:21–53. https://doi.org/10.3758/S13423-012-0333-8.

[8] Salmoni AW, Schmidt RA, Walter CB. Knowledge of results and motor learning: a review and critical reappraisal. Psychol Bull 1984;95:355–86. https://doi.org/10.1037/0033-2909.95.3.355.

[9] Guadagnoll MA, Lee TD. Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. J Mot Behav 2004;36:212–24. https://doi.org/10.3200/JMBR.36.2.212-224.

[10] Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychon Bull Rev 2016;23:1382–414. https://doi.org/10.3758/S13423-015-0999-9.

[11] Hatton AL, Chatfield MD, Cattagni T, Vicenzino B. The effects of vibrating shoe insoles on standing balance, walking, and ankle-foot muscle activity in adults with diabetic peripheral neuropathy. Gait Posture 2024;111:8–13. https://doi.org/10.1016/j.gaitpost.2024.04.008.

[12] Cen S, Ma J, Sun H, Zhang H, Li Y, Mao W, et al. Vibrotactile Foot Device for Freezing of Gait in Parkinson's Disease: A Pilot Study. Mov Disord Clin Pract 2024;11:1241–8. https://doi.org/10.1002/MDC3.14177.

[13] Bowman T, Pergolini A, Carrozza MC, Lencioni T, Marzegan A, Meloni M, et al. Wearable biofeedback device to assess gait features and improve gait pattern in people with parkinson's disease: a case series. J Neuroeng Rehabil 2024;21. https://doi.org/10.1186/S12984-024-01403-Z.

[14] Kirsch P, Helbig M, Rupar D, Baudrexel S, Kell CA. Parkinsonian gait improvement through vibratory stride parameter feedback. Journal of NeuroEngineering and Rehabilitation 2026 23:1 2026;23:226-. https://doi.org/10.1186/S12984-026-02113-4.