

CURRENTS OF CHANGE

GALVANIC VESTIBULAR STIMULATION

INTRODUCTION

Galvanic vestibular stimulation (GVS) is an electrode-mediated method of non-invasive electrical stimulation. Its ability to modulate vestibular neuronal activity through electrical currents makes it a coveted diagnostic and therapeutic tool for vestibular and neurodegenerative disorders.¹ Although more robust clinical research is needed before wide-spread implementation, GVS shows promise as a safe, cost-effective, and accessible therapeutic tool for neurological rehabilitation.²

MODE OF ACTION

GVS procedures administer a small direct current to a patient's mastoids through large-surface electrode current delivery.³ Typically, two electrodes are placed behind each ear of the patient, situated on top of each respective mastoid process. These electrodes deliver the current in a modulated waveform to enact a desired neurophysiological response, such as a head tilt.¹ The fundamental mechanism of GVS relies on the activation of primary otolithic neurons and primary semicircular canal neurons, which are both associated with the vestibular system.¹

The vestibular system is located within the inner ear, and is bordered by the middle ear and temporal bone.⁴ It conveys vital sensory information to the brain regarding head position, spatial orientation, and body motion.⁴ The vestibular system contains a bony and membranous structure known as the vestibular labyrinth, which is targeted by GVS.⁵ The vestibular labyrinth contains the otolithic neurons and the semicircular canals.⁶ The otolithic neurons are associated with the otolith organs, responsible for detecting static and transient head displacements. Static displacements refer to changes in head orientation due to gravitational effects, such as head tilting, which alter the spatial alignment of the head relative to the gravitational force.⁶ In contrast, transient displacements pertain to head movements characterized by linear translation without simultaneous angular rotation (e.g., moving forward in a car without head tilting).³ The semicircular canals and otolithic neurons are responsible for sensing angular head movement in three-dimensional space to relay information to the central nervous system, sustaining balance and spatial orientation.⁶

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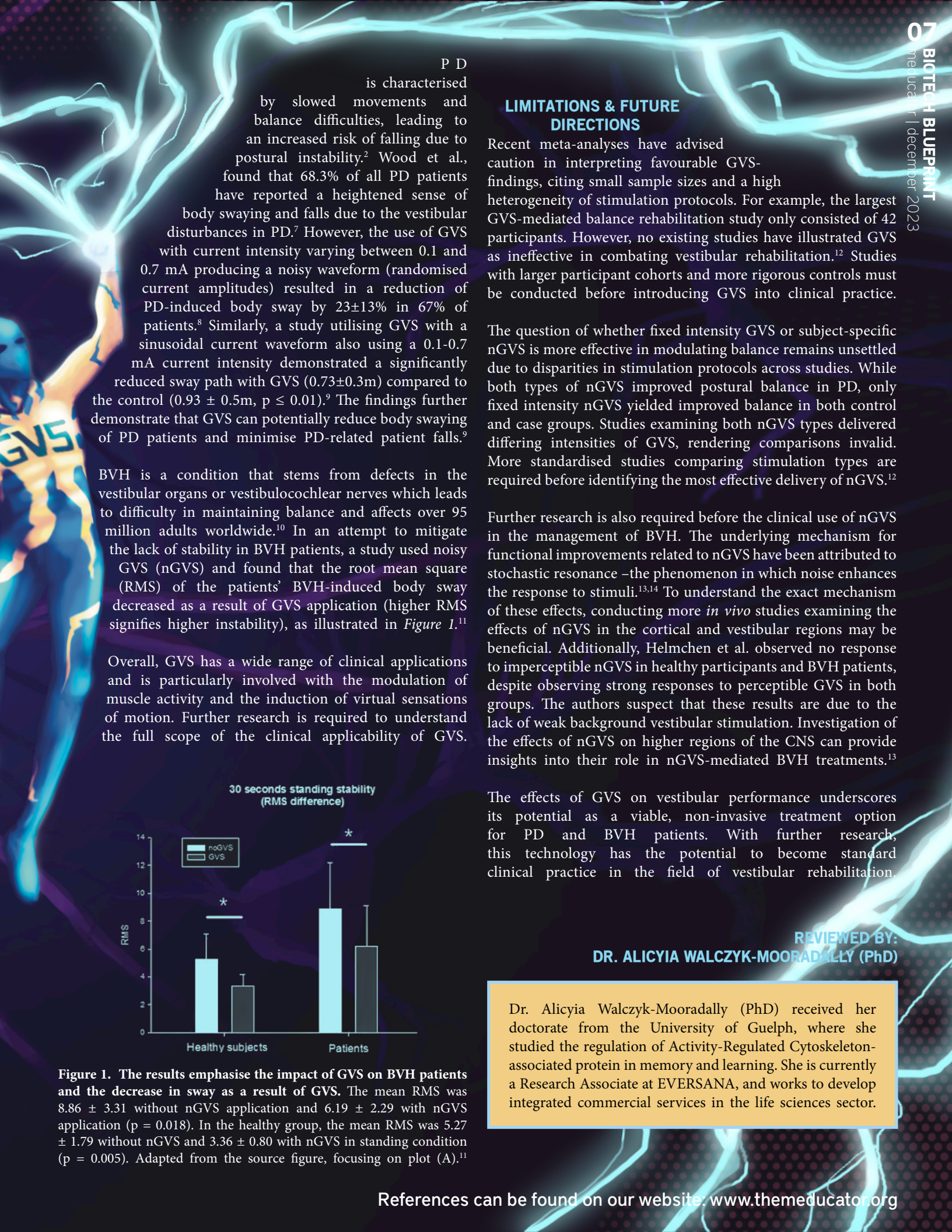
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The electrical current applied through the electrodes to the mastoid process stimulates a flow of ions to the otolithic organs and semicircular canals, activating primary otolithic neurons and primary semicircular canal neurons.³ This induces a variety of vestibular sensations as the brain interprets the signals as changes in head position, movement, or orientation. Simulated vestibular sensations include the modulation of muscle activity and the induction of virtual sensations of motion.² For example, modulation of muscle activity can be seen through the body's attempt to compensate for changes in head tilt by activating the deep cervical flexor muscles.² Similarly, GVS has been used in virtual reality studies to induce virtual sensations that stimulate the action of flying in a plane, including turning left and right, through the application of specific current waveforms to each mastoid process.³

CLINICAL APPLICATIONS

GVS has a wide range of applications with respect to vestibular rehabilitation, particularly in cases of Parkinson's disease (PD) and bilateral vestibular hypofunction (BVH).¹ Current ongoing research is investigating the potential of GVS in addressing the unique challenges of PD, a neurodegenerative disorder that affects movement and balance.² GVS is also being explored in relation to BVH, a pathology in which the vestibular system's function is reduced, leading to spatial disorientation and instability.¹⁰ These studies aim to unlock valuable insights into the specific benefits of GVS for individuals dealing with PD and BVH, paving the way for tailored interventions and improved quality of life for those affected by these conditions.





PD is characterised by slowed movements and balance difficulties, leading to an increased risk of falling due to postural instability.² Wood et al., found that 68.3% of all PD patients have reported a heightened sense of body swaying and falls due to the vestibular disturbances in PD.⁷ However, the use of GVS with current intensity varying between 0.1 and 0.7 mA producing a noisy waveform (randomised current amplitudes) resulted in a reduction of PD-induced body sway by $23 \pm 13\%$ in 67% of patients.⁸ Similarly, a study utilising GVS with a sinusoidal current waveform also using a 0.1-0.7 mA current intensity demonstrated a significantly reduced sway path with GVS ($0.73 \pm 0.3m$) compared to the control ($0.93 \pm 0.5m$, $p \leq 0.01$).⁹ The findings further demonstrate that GVS can potentially reduce body swaying of PD patients and minimise PD-related patient falls.⁹

BVH is a condition that stems from defects in the vestibular organs or vestibulocochlear nerves which leads to difficulty in maintaining balance and affects over 95 million adults worldwide.¹⁰ In an attempt to mitigate the lack of stability in BVH patients, a study used noisy GVS (nGVS) and found that the root mean square (RMS) of the patients' BVH-induced body sway decreased as a result of GVS application (higher RMS signifies higher instability), as illustrated in *Figure 1*.¹¹

Overall, GVS has a wide range of clinical applications and is particularly involved with the modulation of muscle activity and the induction of virtual sensations of motion. Further research is required to understand the full scope of the clinical applicability of GVS.

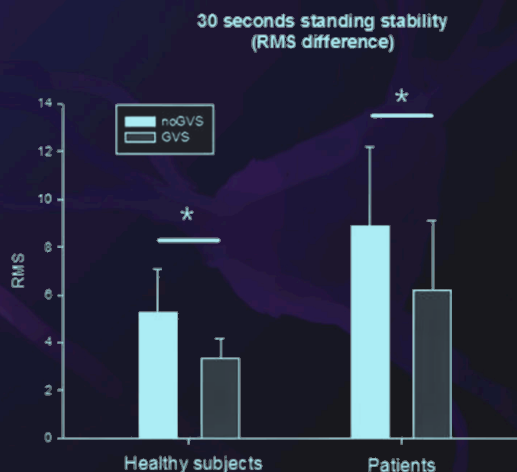


Figure 1. The results emphasise the impact of GVS on BVH patients and the decrease in sway as a result of GVS. The mean RMS was 8.86 ± 3.31 without nGVS application and 6.19 ± 2.29 with nGVS application ($p = 0.018$). In the healthy group, the mean RMS was 5.27 ± 1.79 without nGVS and 3.36 ± 0.80 with nGVS in standing condition ($p = 0.005$). Adapted from the source figure, focusing on plot (A).¹¹

LIMITATIONS & FUTURE DIRECTIONS

Recent meta-analyses have advised caution in interpreting favourable GVS-findings, citing small sample sizes and a high heterogeneity of stimulation protocols. For example, the largest GVS-mediated balance rehabilitation study only consisted of 42 participants. However, no existing studies have illustrated GVS as ineffective in combating vestibular rehabilitation.¹² Studies with larger participant cohorts and more rigorous controls must be conducted before introducing GVS into clinical practice.

The question of whether fixed intensity GVS or subject-specific nGVS is more effective in modulating balance remains unsettled due to disparities in stimulation protocols across studies. While both types of nGVS improved postural balance in PD, only fixed intensity nGVS yielded improved balance in both control and case groups. Studies examining both nGVS types delivered differing intensities of GVS, rendering comparisons invalid. More standardised studies comparing stimulation types are required before identifying the most effective delivery of nGVS.¹²

Further research is also required before the clinical use of nGVS in the management of BVH. The underlying mechanism for functional improvements related to nGVS have been attributed to stochastic resonance –the phenomenon in which noise enhances the response to stimuli.^{13,14} To understand the exact mechanism of these effects, conducting more *in vivo* studies examining the effects of nGVS in the cortical and vestibular regions may be beneficial. Additionally, Helmchen et al. observed no response to imperceptible nGVS in healthy participants and BVH patients, despite observing strong responses to perceptible GVS in both groups. The authors suspect that these results are due to the lack of weak background vestibular stimulation. Investigation of the effects of nGVS on higher regions of the CNS can provide insights into their role in nGVS-mediated BVH treatments.¹³

The effects of GVS on vestibular performance underscores its potential as a viable, non-invasive treatment option for PD and BVH patients. With further research, this technology has the potential to become standard clinical practice in the field of vestibular rehabilitation.

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