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Impact of galvanic vestibular stimulation-induced stochastic resonance on the output of the vestibular system: A systematic review

Dear editor,

With an ageing population, techniques to improve balance function are necessary and likely to reduce the risk of falling due to age-related vestibular dysfunction. Previous work has shown that Galvanic Vestibular Stimulation (GVS) improves balance function in regards to vestibular output measures including Centre of Pressure (CoP) sway and Ocular Vestibular Evoked Myogenic Potentials (oVEMPs) [1,2]. Presumably these improvements are due to the modulation of primary vestibular afferents and vestibular hair cells, possibly via the phenomenon of Stochastic Resonance (SR). Specifically, SR is defined by the application of low-level noise which increases the detectability of subthreshold signals in non-linear systems, including the vestibular system [3]. Major limitations to determining the most effective therapeutic approach to improve balance function using GVS-induced SR are the limited number of studies assessing the direct impact of GVS on vestibular function, and the heterogeneity of reported GVS stimulus parameters used. Indeed, there is a near complete paucity of comparative investigations between the major types of GVS including stochastic and white noise stimuli. Thus, the question arises – whether an optimal set of stimulus parameters to improve vestibular output can be ascertained from the currently available data? We conducted a systematic appraisal of the literature regarding the impact of GVS on vestibular function in healthy individuals as a means for answering this question.

The literature search and selection was conducted using the Population Intervention Comparison Outcome (PICO) procedure. Studies were included if participants were healthy, bipolar binaural trans-mastoid electrical stimulation used, and measured vestibular output (Centre of Pressure sway, Ocular Counter Roll etc.). Conversely, studies were excluded if they used participants neurological or balance related pathologies, animals, non-bipolar binaural trans-mastoid electrical stimulation, non-vestibular measures (i.e. autonomic responses), reviews, conference submissions, non-English publications and abstracts. The literature search was performed using a range of electronic databases (Pubmed, Embase, MEDLINE, Cochrane Library, Scopus, Web of Science) and searching individual and combined terms (i.e. stochastic AND galvanic AND vestibular AND stimulation). The initial search yielded 169 studies, of which, 99 duplicates were removed, and 38 studies removed due to titles or abstracts not fulfilling the inclusion criteria. After analysing 22 full-texts, 12 studies were removed resulting in a small dataset of 10 studies meeting our inclusion criteria for analysis.

The overall quality of the included studies was assessed as fair, based on the Downs and Black study quality checklist. The majority of studies were inadequate in reporting of adverse events, with only two studies reporting this [4,5]. None of the included studies had blinded outcome assessments or adjustments for confounds. Only one study concealed the intervention allocation from both the investigators and participants [1], and only half of the studies reported power analyses to justify sample sizes used [1,3,5–7].

The included studies highlighted improvements to static balance (Centre of Pressure (CoP) sway), dynamic balance (locomotion) or vestibulo-ocular (Ocular Counter Roll; OCR) function in response to GVS. Fig. 1 shows the performance improvements in vestibular output measures across the included studies. An important initial observation is that for both static and dynamic balance measures, with the exception of one study [8], only white noise GVS has been assessed (Fig. 1A and C). In contrast, for vestibulo-ocular measures only stochastic noise GVS has been assessed (Fig. 1D). These disparities limit the ability to compare the efficacy of different stimuli on vestibular output measures, contributing to the difficulty in establishing optimal GVS parameters to improve balance performance.

Efficacy of white noise GVS

White noise GVS has been shown to improve measures of static and dynamic balance with the overall improvement in these measures reported to range from 3.80% to 36.00% (Fig. 1A and C) with varying improvements reported across vestibular output measures. In our analysis, we compared the frequency bandwidth to the percentage improvement in static balance performance and found that stimuli with narrower bandwidths (0–30 Hz) had significantly greater performance improvement than stimuli with broad bandwidths (0.1–640 Hz; 16.20% vs 7.849%; $p = 0.008$; Fig. 1B). When the bandwidth is narrowed further (0.01–10 Hz), white noise GVS does not produce greater improvements in dynamic balance (stride time and stride length) [3] when compared with 0–30 Hz bandwidth [9,10] (Fig. 1C). This suggests that for static and dynamic balance, a 0–30 Hz white noise GVS may prove to be the most effective frequency bandwidth. However, stochastic noise GVS cannot be discounted since its impact has not yet been assessed using comparable frequency bandwidths, or indeed, for dynamic balance function at all. Work providing this information may be crucial for establishing the most effective GVS parameters for use in treatment of balance dysfunction.

Efficacy of stochastic noise GVS

Unlike white noise GVS, only one study has used stochastic noise GVS to measure static balance performance. In that study, Mulavara

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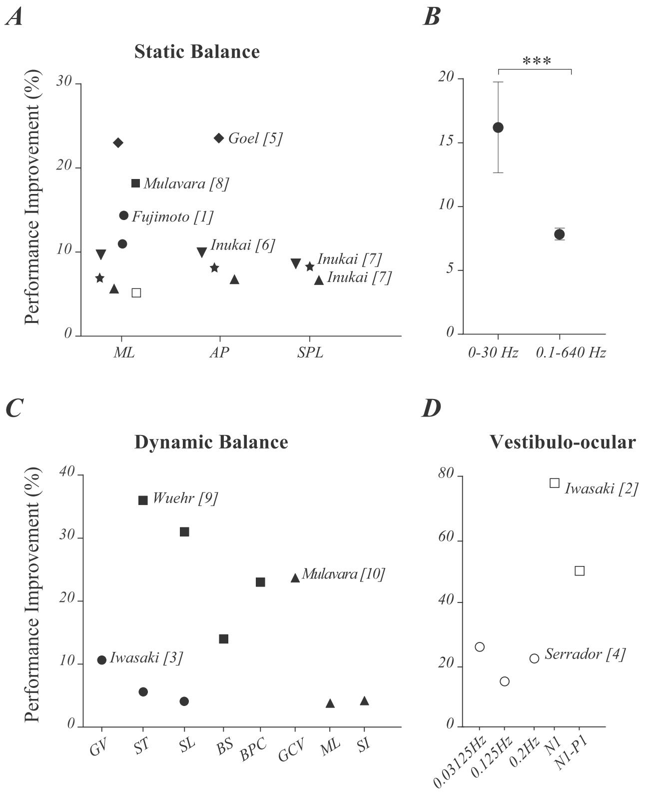

Fig. 1. ***A*** Normalised improvements in mediolateral (ML) sway, anteroposterior (AP) sway and Sway Path Length (SPL) in response to GVS-induced SR. Triangles denote 1.0 mA and stars denote 0.4 mA GVS applied during the same study [7]. Two closed circles represent a 3 hour GVS (higher circle, 14.0%) and a 30 minute GVS (lower circle, 11.0%) [1]. ***B*** 0–30 Hz bandwidth white noise GVS is more effective at improving static balance than 0.1–640 Hz bandwidth white noise GVS (16.20% vs 7.85%, two-tailed unpaired *t*-test $p = 0.0082$). ***C*** Normalised improvements to gait function in response to GVS-induced SR. GV, Gait Velocity; ST, Stride Time; SL, Stride Length; BS, Base of Support; BPC, Bilateral Phase Coordination; GCV, Gait Cycle-time Variability; ML, Mediolateral RMS; SI, Superior-Inferior RMS. ***D*** Normalised improvements to reflexive eye movements in response to GVS-induced SR. Ocular Counter Roll (OCR) gain measured at three rotational frequencies (0.03125, 0.125 and 0.2 Hz). Amplitudes of the first negative peak (N1) and the second positive peak (N1–P1) of ocular Evoked Myogenic Potentials (oVEMP). Figures ***A***–***D***, open symbols denote stochastic noise GVS and closed symbols white noise GVS and error bars indicate the standard error of the mean. *** = $p < 0.01$.

et al. [8] used 1–2 Hz bandwidth stochastic noise GVS and observed improvements to balance stability, although a 0–30 Hz bandwidth white noise produced greater improvements (Fig. 1A). While this strengthens the idea that a 0–30 Hz bandwidth white noise is an effective stimulus, it is important to note that the authors did not apply stochastic noise GVS at a comparable 0–30 Hz bandwidth. This leaves open the possibility that stochastic noise GVS is equally or more effective than white noise GVS. When considering vestibulo-ocular measures, only two studies have applied stochastic noise GVS. Both found significant improvements in OCR [4] and oVEMPs [2] ranging from 15.33 to 75.9% (Fig. 1D). Crucially, neither study assessed white noise GVS, again limiting the ability to determine optimal GVS character for improving vestibulo-ocular function.

Conclusions

The apparent disconnect between stimulus character and parameters and vestibular output measures prevents most direct comparison to determine the most effective GVS stimulus to improve balance function. Further, the small number of studies meeting our inclusion criteria of directly assessing vestibular output in response to GVS, highlights the current difficulty in establishing clinically useful stimulus parameters. However, based on our appraisal of the included literature, GVS within 0–30 Hz bandwidth appears to be consistently beneficial. To confirm this however, it is important that future work apply stochastic and white noise GVS with the same parameters (i.e. frequency bandwidth) to assess its impact on each vestibular output measure directly.

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Author statement

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Declaration of competing interest

The authors have no conflicts of interest to declare.

References

[1] Fujimoto C, Yamamoto Y, Kamogashira T, Kinoshita M, Egami N, Uemura Y, et al. Noisy galvanic vestibular stimulation induces a sustained improvement in body balance in elderly adults. Sci Rep 2016;6:37575.
[2] Iwasaki S, Karino S, Kamogashira T, Togo F, Fujimoto C, Yamamoto Y, et al. Effect of noisy galvanic vestibular stimulation on ocular vestibular-evoked myogenic Potentials to bone-conducted vibration. Front Neurol 2017;8:26.
[3] Iwasaki S, Fujimoto C, Egami N, Kinoshita M, Togo F, Yamamoto Y, et al. Noisy vestibular stimulation increases gait speed in normals and in bilateral vestibulopathy. Brain Stimul 2018;11(4):709–15.
[4] Serrador JM, Deegan BM, Geraghty MC, Wood SJ. Enhancing vestibular function in the elderly with imperceptible electrical stimulation. Sci Rep 2018;8(1):336.
[5] Goel R, Kofman I, Jeevarajan J, De Dios Y, Cohen HS, Bloomberg JJ, et al. Using low levels of stochastic vestibular stimulation to improve balance function. PLoS One 2015;10(8):e0136335.
[6] Inukai Y, Masaki M, Otsuru N, Saito K, Miyaguchi S, Kojima S, et al. Effect of noisy galvanic vestibular stimulation in community-dwelling elderly people: a randomised controlled trial. J NeuroEng Rehabil 2018;15(1):63.
[7] Inukai Y, Otsuru N, Masaki M, Saito K, Miyaguchi S, Kojima S, et al. Effect of noisy galvanic vestibular stimulation on center of pressure sway of static standing posture. Brain Stimul 2018;11(1):85–93.
[8] Mulavara AP, Fiedler MJ, Kofman IS, Wood SJ, Serrador JM, Peters B, et al. Improving balance function using vestibular stochastic resonance: optimizing stimulus characteristics. Exp Brain Res 2011;210(2):303–12.
[9] Wuehr M, Nusser E, Krafczyk S, Straube A, Brandt T, Jahn K, et al. Noise-enhanced vestibular input improves dynamic walking stability in healthy subjects. Brain Stimul 2016;9(1):109–16.
[10] Mulavara AP, Kofman IS, De Dios YE, Miller C, Peters BT, Goel R, et al. Using low levels of stochastic vestibular stimulation to improve locomotor stability. Front Syst Neurosci 2015;9:117.

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