Medical Research Archives

European Society of Medicine

OPEN ACCESS

Published: November 30, 2023

Citation: Kukurin GW and Audren CD, 2023. The Emerging Role of Vestibular Stimulation in Brain Rehabilitation: A Representative Case Report, Medical Research Archives, [online] 11(11). https://doi.org/10.18103/mra.v11i11.4595

DOI
https://doi.org/10.18103/mra.v11i11.4595

ISSN: 2375-1924

CASE REPORT

The Emerging Role of Vestibular Stimulation in Brain Rehabilitation: A Representative Case Report

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ABSTRACT.
The number of literature reports suggesting that various types of electrical, optokinetic, caloric, and mechanical vestibular stimulation may enhance recovery of function in patients suffering from traumatic and degenerative brain disorders is growing. This case report describes the integration of vestibular stimulation techniques into a rehabilitation treatment plan of a traumatically brain injured 16-year-old patient who had failed to sustain recovery after a course of standard care. His intractable signs and symptoms included headache, brain fog/mild cognitive impairment and disequilibrium which made participation in his chosen sport, hockey, virtually impossible. His symptoms developed following a concussion while playing hockey. He was treated by the team's designated sports specialist and eventually cleared to return to play, however he was rapidly re-concussed. At the time he presented for evaluation, a battery of tests was conducted and clearly supported the reoccurrence of his symptoms. His baseline scores were Graded Symptom Checklist symptom severity 46, Standard Assessment of Concussion 25/30, BESS Balance Score 14, Trails Test A 15.0, Trails Test B 27.4, Processing Speed Task 63, Reaction time simple 255 and Reaction time choice 469. Standard methods of rehabilitation including Gaze Stabilization Exercises and Progressive Balance Exercises were augmented with vestibular stimulation through the use of skull vibrations and optokinetic stimulation. After 18 treatments over approximately six weeks of rehabilitation augmented with vestibular stimulation, findings associated with mTBI normalized and he was able to resume his full participation in sporting activities. His post treatment scores were. Graded Symptom Checklist symptom severity 1, Standard Assessment of Concussion 24/30, BESS Balance Score 5, Trails Test A 12.4, Trails Test B 34.0, Processing Speed Task 64, Reaction time simple 245 and Reaction time choice 385. He remained asymptomatic at 4 months follow-up post discharge and is participating fully in team hockey activities. This case report describes the integration of vestibular stimulation into neurorehabilitation protocols which appeared to be associated with sustained reduction in disability and improved treatment-refractory symptoms in a patient with traumatic brain injury. It adds to the growing knowledgebase supporting the role of vestibular stimulation as an adjunct modality in the rehabilitation of brain disorders.

Introduction

Transcutaneous electrical stimulation of the vestibular nerve (GVS) was first ascribed to Purkinje in 1820 and has since been clinically investigated by neurologists and neuroscientists in subsequent years. [1]

Optokinetic stimulation (OKS) reflexively activates the vestibular system in response to visual input that creates the perception of movement. [2] Likewise caloric thermal stimulation (CVS) [3] and skull vibrations (VSV) of different types and at various anatomical locations [4–8] have also been shown to noninvasively activate the vestibular system.

Lopez recently reviewed studies of the effects of various methods of vestibular stimulation on the central nervous system. Creating a map of the widespread activation of the cerebral cortex in response to vestibular stimulation.[9] This widespread inter-connectivity has led some investigators to postulate that vestibular activation of diverse cortical structures may produce functional improvement in patients suffering from neurodegenerative or traumatic brain disorders.[10–13]

Optokinetic kinetic stimulation (OKS) has been reported to enhance neurological function in a number of published reports. These include dramatic improvement in a case of ataxia, [14] a similar improvement in a patient who was disabled from multiple sclerosis. [15] OKS was also found to improve signs of hemispatial neglect in stroke patients. Functional MRI and PET studies suggest that the improved neurological function observed clinically might be attributable to partial reactivation of the distributed, multisensory vestibular network in the lesioned hemisphere in these stroke patients. [16] OKS may also induce a unilateral change of the mean Center of Pressure in both sitting and standing, stroke patients. This suggests that OKS promotes a shift in weight-bearing in patients, an important early component in neurorehabilitation of brain injured patients. [17]

Caloric vestibular stimulation occurs through the induction of a temperature gradient across the semicircular canals of the vestibular apparatus by filling the auditory canal with cold and/or warm air or water. Functional brain-imaging studies have documented the activation of the contralateral cortical and subcortical brain regions in response to CVS. This temperature induced vestibular activation has demonstrated wide ranging effects on a number of visual and cognitive phenomena, as well as on post-stroke conditions, mania and chronic pain states. [18]

Similarly activation of the otolith vestibular end organs through application of 100 and 500 hertz frequency tones to the skull has been convincingly demonstrated and form the foundation for vestibular evoked myogenic potential (VEMP) testing of otolith function.[19–22] Indeed, studies of vestibular stimulation through skull vibration appear to suggest a positive influence on gait performance. Demonstrating improved spatial-temporal parameters including step length, step time, foot clearance, and foot clearance variability while walking on inclines. All of which indicate improved gait associated with skull vibration-induced vestibular stimulation[7]

While observations of transiently improved neurological function associated with various forms vestibular stimulation are increasingly reported, questions about the long-term durability of this improved function remain unanswered.

In this case, we wanted to determine if the addition of vestibular activation as an adjunct to standard neurorehabilitation techniques would provide a more long-lasting recovery in a brain injured elite athlete who failed to respond adequately to previous treatment. We chose optokinetic stimulation and skull vibration at 100 and 500hz frequencies, as simple and inexpensive methods to activate the patient's vestibular system while he performed standard neurorehabilitation protocols.

Case Report: The patient was a 16-year-old male hockey player who sustained a concussion the symptoms of which proved resistant to treatment. After securing written informed consent from his parents, he was evaluated and ultimately treated for intractable symptoms of mild Traumatic Brain Injury (mTBI).

Treatment was based on stimulation of the known widespread connectivity between the cerebellar, vestibular, and reflexogenic systems for the purpose of facilitating cortical communications. The individual therapies were chosen based on their ability to challenge or stress the specific systems. The patient's response to specific interventions was continuously evaluated during each treatment session and monitored for signs of improved function. Effort was made to address specific vestibular deficiencies in each treatment.

The examination included routine orthopedic, neurologic, and physical assessments. In addition, the C3Logix concussion assessment software package was employed. This software quantitates concussion symptoms allowing for the comparison of individual patient data with a normative database, it also creates baseline and follow up scoring for comparison. The following domains with brief descriptions follow.

Graded Symptom Checklist (GSC) - 27 question physical symptom index which captures mode of test administration. Symptom severity, Standard Assessment of Concussion (SAC) - Combined with the GSC, this test compares to the industry standard test called "SCAT" which evaluates immediate memory, delayed memory, concentration, and orientation. Balance (BESS) - The subject performs the test and is graded on errors (traditional measure) as well as Sway Volume which is captured from the accelerometers and gyroscope on an iPad, Trails Test - This test is a standard neuro-psychology test that is a "connect the dots" pattern with two parts. The first part is numbers only and the second part introduces set switching by using both numbers and letters, Processing Speed Task (PST) - This test is derived from a standard neuro- psychology test called "symbol-digit modalities". It evaluates processing speed, short-term memory, and visuo-spatial scanning, as well as rate of learning, Reaction time (RT) - This task evaluates simple and choice reaction time. Choice reaction time provides a response and distractor stimulus. The subject must inhibit motion on the blue light (distractor) side and respond on the green light side.

Based on physical and computerized assessment, a treatment plan was formulated for this patient.

Gaze Stabilization Exercises are designed to synchronize and integrate signals originating from the semi-circular canals of the vestibular apparatus with neck muscle proprioceptive information and input from the oculomotor circuitry. They are performed with the eyes/gaze fixated on a stationary target while the patient deliberately and repetitively performs head movements. There are two fundamental exercises, one where the patient maintains gaze fixation while flexing and extending the head and neck, frequently referred to as a "Yes-Yes" head nod exercise. The second exercise, has the patient fixate their gaze while rotating their head to the left and right, known as a "No-No" exercise. Exercise progressions and variations of these two basic exercises are described in detail by Herdman.[23]

Isometric neck exercises, holding 10 seconds each side, front and back, were performed prior to the gaze stability exercises to enhance cervical stability/strength. Gaze stability exercise incorporated laser guided feedback initially done standing and later progressing to a perturbed/ foam surface as an added challenge once the patient became smoother/stronger.

Progressive Balance Exercises are a series of postures and conditions that incrementally increase the demand on the balance network and are routinely used for the rehabilitation of patients experiencing postural instability. The typical progression is standing with feet together, progressing to tandem stance (heel-to-toe) with the right foot forward and then repeated with the left foot forward, finally single leg stance, left vs. right leg. The patient works to maintain their balance in these various postures. As a patient's postural stability improves at the less challenging posture, they gradually progress to the next level of difficulty. Two conditions are incrementally added to further challenge the balance network. The first is performing the aforementioned postures on a stable surface versus a foam pad (perturbed) surface. The second condition is with the patient's eyes open versus eyes closed. Postural stability is the product of multisensory integration of mainly visual, proprioceptive, and vestibular input. The eyes closed and foam pad conditions effectively mute the visual and proprioceptive signals from the lower extremities respectively. With the input from the visual and proprioceptive channels muted, the multisensory input may be reweighted towards vestibular signals. [24]

Skull Vibration to stimulate the vestibular system was administered utilizing a tone generating smartphone app (Tone Pacer Pro) in conjunction with widely available bone conducting headphones (Trekz Titanium headphones, AfterShokz Corp.). The specific tone parameters used in this case (left ear 100hz, right ear 500hz and beeps per minute 50) were determined by the observation of improved postural stability during balance testing at these specific settings. The specific settings were employed to administer skull vibration during progressive balance training exercises.

Optokinetic Stimulation can be administered in a number of ways. To invoke reflex activation of the optokinetic neural circuitry and thus stimulate the patient's vestibular system, a strip containing alternately red and white rectangles is passed through the patient's visual field. The moving pattern creates a smooth pursuit eye movement and a reflexive refixation saccade in the direction opposite from the direction of the smooth pursuit movement. This is known as an optokinetic nystagmus which has been associated with the vestibular perception of body movement. The OKS in this case was administered in a diagonal direction, moving from the top downward while the patient performed progressive balance exercises for the purpose of adding vestibular stimulation to the balance training exercises.

The patient completed 18 such treatment sessions over the course of about six weeks. He was assessed before his initial rehabilitation session (T0), interim and at discharge (T2).

Outcome: His baseline scores were Graded Symptom Checklist symptom severity 46, Standard Assessment of Concussion 25/30, BESS Balance Score 14, Trails Test A 15.0, Trails Test B 27.4, Processing Speed Task 63, Reaction time simple 255 and Reaction time choice 469. Standard methods of rehabilitation including Gaze Stabilization Exercises and Progressive Balance Exercises were augmented with vestibular stimulation through the use of skull vibrations and optokinetic stimulation. After 18 treatments over approximately six weeks of rehabilitation augmented with vestibular stimulation, findings associated with mTBI normalized and he was able to resume his full participation in sporting activities. His post treatment scores were. Graded Symptom Checklist symptom severity 1, Standard Assessment of Concussion 24/30, BESS Balance Score 5, Trails Test A 12.4, Trails Test B 34.0, Processing Speed Task 64, Reaction time simple 245 and Reaction time choice 385. He remained asymptomatic at 4 months follow-up post discharge and is participating fully in team hockey activities.

Table 1: Change From Baseline

C3Logix Domain*	Baseline T(0)	Discharge T(2)	Change (Delta)	50th Norm**
GSC	46	1	45	2
SAC	25/30	24/30	1	26
BESS	14	5	9	13
Trails A	15.0	12.4	2.6	22.69
Trails B	27.4	34.0	+6.6	46.98
PST	63	64	+1	57
RT Simple	255	245	10	284.583
RT Choice	469	385	84	412

* See text section for description.
** C3Logix 50th Percentile Normative Database.
See discussion section for interpretation.

Discussion

The patient, who was an elite athlete, was at great risk of not returning to hockey and, at the time of the evaluation, he had already accepted that possibility. His injuries had been affecting his ability to even go to school. Athletes with mTBI may enter a depressive state with post-concussion symptoms due to the effect on their ability to play sports, train, go to school and to socialize.

Head injury often involves axonal damage and neuroinflammation. Increased symptoms with additional head injury may be explained by the neurometabolic cascade, both structural and chemical changes, seen in mTBI cases.

Sawyer et al. (2016) commented that it can take 10-30 days post injury for this cascade to stabilize during which is imperative to minimize any risk of further injury. They also acknowledged that adolescents have a longer recovery from concussion and caution is needed when treating patients with persistent symptoms.[25]

The improvements in this case study illustrate the benefits of adding vestibular stimulation in reducing disability and intractable symptoms associated with mTBI. Although the initial (baseline) C3Logix testing shows our athlete performed better than the normative database on most components with the exception of Choice Reaction Time (RT), Balance (BESS) and Symptom Severity, he experienced rapid improvement in his most troubling symptoms within the first week of our neurorehabilitation therapies. Each testing component improved substantially and even better than the normative data (50th percentile). Symptom Severity and Choice RT showed the greatest improvements. During the weeks of treatment, the patient acknowledged that his performance on the ice was improving even in regard to aspects he felt were already strong. Upon discharge, the patient stated that he felt better than he did pre-season.

Addressing the vestibular impairments associated with mTBI has shown to be effective in this case as vestibular rehabilitation not only affects the vestibular system, but also the somatic and visual systems. Vestibular stimulation activates components of the cerebellum, vestibular systems – both semicircular canals and otoliths, which in turn communicate with the brainstem, cortex, and spinal cord. This might explain the improvement in light and sound sensitivity, concentration and focus, vision and not just balance.

Numerous methods exist to activate the vestibular end organs with integration of these ascending signals into diverse regions of the brain (Lopez). [9] They range in complexity from a simple striped strip that is manually moved through the visual field, to human centrifuges that administer whole body rotations in multiple planes. [26]

The use of skull vibration, gaze stabilization and OKS is very effective, and exhibit ease of use in a general clinic or primary care environment. These therapies frequently demonstrate immediate symptomatic changes in our patient without any report of increased discomfort. They activate the vestibulo-ocular reflex (VOR) via semicircular canal stimulation as well as the vestibulospinal reflex (VSR) and vestibulo-collic reflex (VCR). The VOR stabilizes gaze/vision when the head is in motion, the VCR stabilizes the head via the neck musculature, and the VSR stabilizes the head and body for postural stability.

We believe the improvements reported in the case, are most likely due to the various interventions being modified accordingly as needed and biased towards those stimulations that appeared to promote improved function. This adds to the strength and benefit of using specific vestibular based therapies based on the individual compared to a 'generic' (standard/traditional) concussion rehabilitation program. Earlier intervention utilizing vestibular stimulation may have been essential to this athlete's recovery. Park et al. (2018) found that adolescents suffering with persistent symptoms should have earlier vestibular evaluation and individualized vestibular rehabilitation therapy (VRT) and found this to potentially be better than physical and cognitive rest. [27]

Since concussions affect individuals differently, measurement tools, such as the C3Logix system used in our case study, show potential in testing both Baseline and post injury as a convenient way to measure impairments and monitor improvements of the therapies implemented. This benefit of comparison after an injury can assist in decisions made regarding impaired areas to treat and also for return to play. [28] There may be, however, limitations to the C3Logix system due to yearly cost and using an iPad.[28] Baseline testing, preseason, would have been beneficial in this case, however, using the C3Logix technology and its database allowed for comparison to a normative database of athletes of the same age.

This case study illustrates that significant changes can be made in a single provider setting and thus potentially reduce costs and time lost in seeking treatment between multiple providers. This may also improve patient compliance in that they can receive effective treatment at one location. As each case is patient dependent, so should be the care/therapy they receive. Every effort should be made to refer to additional providers as the case requires.

There is a clear need for future additional studies to address these issues in a controlled manner and a larger patient population.

The exact mechanism or mechanisms responsible for the apparent clinical improvement reported in patients suffering from diverse neurological conditions following vestibular stimulation remains unknown.

Likewise, the superior type of vestibular stimulation, if one exists; the optimal parameters for intensity, frequency and duration of stimulation as well as the determination of appropriate patient populations for these types of stimulations demand formal investigation.

Conclusion

Although admitting the limitations of a single case, this report nevertheless, provides quantitative data supporting growing evidence that vestibular stimulation when added to standard rehabilitation of a brain injured patient, may improve clinical outcomes. The long-lasting improvements reported in a case of treatment-resistant mTBI supports the argument for more research into the role of vestibular stimulation as an adjunct to standard rehabilitation of patients suffering from various brain afflictions.

Conflicts of Interest Statement

GWK designed and developed the Tone Pacer App software used to administer vestibular skull vibration.
CDA has no conflicts of interest to report.

References

1. Ernst A. [Galvanic labyrinth stimulation--medical history aspects]. *Laryngorhinootologie*. 1994;73(6):324-325. doi:10.1055/s-2007-997140
2. Han C, Ress D, Ramos Nunez AI, de la Rosa N, Li S, Sulzer JS. Brainstem BOLD response to visual and acoustic stimuli. *Annu Int Conf IEEE Eng Med Biol Soc IEEE Eng Med Biol Soc Annu Int Conf*. 2020;2020:2889-2892. doi:10.1109/EMBC44109.2020.9175794
3. Suzuki M, Kitano H, Ito R, et al. Cortical and subcortical vestibular response to caloric stimulation detected by functional magnetic resonance imaging. *Brain Res Cogn Brain Res*. 2001;12(3):441-449. doi:10.1016/s0926-6410(01)00080-5
4. Brantberg K, Westin M, Löfqvist L, Verrecchia L, Tribukait A. Vestibular evoked myogenic potentials in response to lateral skull taps are dependent on two different mechanisms. *Clin Neurophysiol Off J Int Fed Clin Neurophysiol*. 2009;120(5):974-979. doi:10.1016/j.clinph.2009.03.008
5. Chien JH, Mukherjee M, Kent J, Stergiou N. Mastoid vibration affects dynamic postural control during gait in healthy older adults. *Sci Rep*. 2017;7:41547. doi:10.1038/srep41547
6. Halmagyi GM, Yavor RA, Colebatch JG. Tapping the head activates the vestibular system: a new use for the clinical reflex hammer. *Neurology*. 1995;45(10):1927-1929. doi:10.1212/wnl.45.10.1927
7. Sun Y, Zhu D, Song H, Chien JH. Vibrations on mastoid process alter the gait characteristics during walking on different inclines. *PeerJ*. 2023;11:e15111. doi:10.7717/peerj.15111
8. Lin CM, Wang SJ, Young YH. Ocular vestibular evoked myogenic potentials via bone-conducted vibrations applied to various midsagittal cranial sites. *Otol Neurotol Off Publ Am Otol Soc Am Neurotol Soc Eur Acad Otol Neurotol*. 2010;31(1):157-161. doi:10.1097/MAO.0b013e3181c2a0e1
9. Lopez C. Lopez C. (2015) Vestibular Cortex. In: Arthur W. Toga, editor. Brain Mapping: An Encyclopedic Reference, vol. 2, pp. 305-312. Academic Press: Elsevier.. In: *Brain Mapping: An Encyclopedic Reference*. Vol 2. Elsevier; 2015:305-312.
10. Wilkinson D. Caloric and galvanic vestibular stimulation for the treatment of Parkinson's disease: rationale and prospects. *Expert Rev Med Devices*. 2021;18(7):649-655. doi:10.1080/17434440.2021.1935874
11. Schiff ND, Pulver M. Does vestibular stimulation activate thalamocortical mechanisms that reintegrate impaired cortical regions? *Proc Biol Sci*. 1999;266(1417):421-423. doi:10.1098/rspb.1999.0654
12. Zubko O, Wilkinson D, Langston D, Sakel M. The effect of repeated sessions of galvanic vestibular stimulation on target cancellation in visuo-spatial neglect: preliminary evidence from two cases. *Brain Inj*. 2013;27(5):613-619. doi:10.3109/02699052.2013.767938
13. Black RD, Chaparro E. Time-varying caloric vestibular stimulation for the treatment of neurodegenerative disease. *Front Aging Neurosci*. 2022;14:1049637. doi:10.3389/fnagi.2022.1049637
14. Chitambira B, McConaghy C. Use of optokinetic chart stimulation to restore mobility and reduce ataxia in a patient with pseudo-Cushing ataxia. *BMJ Case Rep*. 2018;2018: bcr2018225346, bcr-2018-225346. doi:10.1136/bcr-2018-225346
15. Chitambira B, McConaghy C. Use of optokinetics based OKCSIB protocol in restoring mobility in primary progressive MS. *BMJ Case Rep*. 2017;2017:bcr2017220384, bcr-2017-220384. doi:10.1136/bcr-2017-220384
16. Moon S, Lee B, Na D. Therapeutic effects of caloric stimulation and optokinetic stimulation on hemispatial neglect. *J Clin Neurol Seoul Korea*. 2006;2(1):12-28. doi:10.3988/jcn.2006.2.1.12
17. Komagata J, Sugiura A, Takamura H, Ohta A, Kitama T. Effect of optokinetic stimulation on weight-bearing shift in standing and sitting positions in stroke patients. *Eur J Phys Rehabil Med*. 2021;57(1):13-23. doi:10.23736/S1973-9087.20.06184-5
18. Been G, Ngo TT, Miller SM, Fitzgerald PB. The use of tDCS and CVS as methods of non-invasive brain stimulation. *Brain Res Rev*. 2007;56(2):346-361. doi:10.1016/j.brainresrev.2007.08.001
19. Dlugaiczyk J, Burgess AM, Curthoys IS. Activation of Guinea Pig Irregular Semicircular Canal Afferents by 100 Hz Vibration: Clinical Implications for Vibration-induced Nystagmus and Vestibular-evoked Myogenic Potentials. *Otol Neurotol Off Publ Am Otol Soc Am Neurotol Soc Eur Acad Otol Neurotol*. 2020;41(7):e961-e970. doi:10.1097/MAO.0000000000002791
20. Greenwalt NL, Patterson JN, Rodriguez AI, Fitzpatrick D, Gordon KR, Janky KL. Bone Conduction Vibration Vestibular Evoked Myogenic Potential (VEMP) Testing: Reliability in Children, Adolescents, and Young Adults. *Ear Hear*. 2021;42(2):355-363. doi:10.1097/AUD.0000000000000925

21. Curthoys IS, Vulovic V, Burgess AM, Sokolic L, Goonetilleke SC. The response of guinea pig primary utricular and saccular irregular neurons to bone-conducted vibration (BCV) and air-conducted sound (ACS). *Hear Res*. 2016;331:131-143. doi:10.1016/j.heares.2015.10.019
22. Dennis DL, Govender S, Colebatch JG. Properties of cervical and ocular vestibular evoked myogenic potentials (cVEMPs and oVEMPs) evoked by 500 Hz and 100 Hz bone vibration at the mastoid. *Clin Neurophysiol Off J Int Fed Clin Neurophysiol*. 2016;127(1):848-857. doi:10.1016/j.clinph.2015.06.027
23. Herdman S, Clendaniel R. *Vestibular Rehabilitation*. 4e ed. McGraw Hill; 2014. https://fadavispt.mhmedical.com/content.aspx?bookid=1878&sectionid=140994821
24. Appiah-Kubi KO, Wright WG. Vestibular training promotes adaptation of multisensory integration in postural control. *Gait Posture*. 2019;73:215-220. doi:10.1016/j.gaitpost.2019.07.197
25. Sawyer Q, Vesci B, McLeod TCV. Physical Activity and Intermittent Postconcussion Symptoms After a Period of Symptom-Limited Physical and Cognitive Rest. *J Athl Train*. 2016;51(9):739-742. doi:10.4085/1062-6050-51.12.01
26. Carrick F, Pagnacco G, Oggero E, et al. The effects of whole body rotations in the pitch and yaw planes on postural stability. *Funct Neurol*. 2011;1:167-179.
27. Park K, Ksiazek T, Olson B. Effectiveness of Vestibular Rehabilitation Therapy for Treatment of Concussed Adolescents With Persistent Symptoms of Dizziness and Imbalance. *J Sport Rehabil*. 2018;27(5):485-490. doi:10.1123/jsr.2016-0222
28. Borges A, Raab S, Lininger M. A comprehensive instrument for evaluating mild traumatic brain injury (mtbi)/concussion in independent adults: a pilot study. *Int J Sports Phys Ther*. 2017;12(3):381-389.