Literature Review

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# Applications of vestibular-evoked myogenic potentials: a systematic literature review

## Aplicações dos potenciais evocados miogênicos vestibulares: revisão sistemática de literatura

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### ABSTRACT

**Purpose:** To review the scientific literature on the main techniques used to generate vestibular-evoked myogenic potential (VEMP) and its clinical applications. **Research strategy:** A search for articles describing VEMP recording methods and applications was conducted in the PubMed, Web of Science, MEDLINE, Scopus, LILACS and SciELO databases. The search was limited to articles published in English, Portuguese, and Spanish between January 2012 and May 2018. **Selection criteria:** Articles addressing the technical aspects for performing ocular, cervical or soleus VEMP with auditory or galvanic stimulation and articles on the clinical applications of VEMP were included in this review, whereas articles repeated in the databases, literature reviews, case reports, letters, and editorials were excluded. **Results**: The search strategy resulted in the selection of 28 articles. The studies evidenced three methods of VEMP recording: responses from the cervical, ocular and soleus muscle. Clinical applications of VEMP included Meniere's disease, vestibular neuritis, superior semicircular canal dehiscence syndrome, Parkinson's disease, central ischemic lesions, and motor myelopathies. **Conclusion:** Regardless of the recording technique, VEMP has proved to be useful as a complementary tool for the diagnosis of peripheral and central vestibular diseases.

**Keywords:** Vestibular Nuclei; Vestibular-evoked Myogenic Potential; Postural balance; Vestibular function tests; Vestibular nerve

### RESUMO

**Objetivos:** Revisar a literatura científica sobre as principais técnicas usadas para gerar o potencial evocado miogênico vestibular (VEMP) e suas aplicações clínicas. **Estratégia de pesquisa:** Os artigos que descrevem os métodos de registro e as aplicações do VEMP foram localizados nas bases de dados PubMed, Web of Science, MEDLINE, Scopus, LILACS e SciELO. O levantamento realizado limitou-se aos artigos publicados nos idiomas Inglês, Português e Espanhol, entre janeiro de 2012 e maio de 2018. **Critérios de seleção:** Artigos sobre os aspectos técnicos para a realização do VEMP ocular, cervical ou do músculo sóleo, com estimulação auditiva ou galvânica e artigos sobre as aplicações clínicas do VEMP foram incluídos; artigos repetidos nas bases de dados, artigos de revisão de literatura, relato de casos, cartas e editoriais foram excluídos. **Resultados:** A estratégia de busca resultou na seleção de 28 artigos. Os estudos evidenciaram três métodos de registro do VEMP: cervical, ocular e no músculo sóleo. As aplicações clínicas do VEMP incluíram doença de Ménière, neurite vestibular, síndrome da deiscência do canal semicircular superior, doença de Parkinson, lesões centrais isquêmicas e mielopatias motoras. **Conclusão:** Independentemente da técnica de registro, o VEMP mostrou-se útil como ferramenta complementar para o diagnóstico de doenças vestibulares periféricas e centrais.

**Palavras-chave:** Núcleos vestibulares; Potencial evocado miogênico vestibular; Equilíbrio postural; Testes de função vestibular; Nervo vestibular

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## INTRODUCTION

Vestibular-evoked myogenic potential (VEMP) is an electrophysiological method used to assess integration of the otolith organs and vestibular nerves with the brainstem and the muscular system. Therefore, it is a complementary exam that presents the differential of evaluating the central vestibular function, and it is related to a disynaptic reflex that has been considered to investigate brainstem function[1,2].

The VEMP is generated from the muscle reflex responses resulted of the vestibulo-ocular, the vestibulomasseteric and the vestibulospinal reflexes. These reflexes depend on the functional integrity of the utricular and saccular maculae, the inferior and superior vestibular nerves, the vestibular nuclei, the central vestibular pathways, and the neuromuscular plaques[3,4]. Changes in The VEMP are observed if any of the listed structures present injury.

The VEMP has been utilized to study a variety of vestibular diseases. Among peripheral diseases, Meniere's disease[5,6], vestibular neuritis[7], superior semicircular canal dehiscence[8-10], large vestibular aqueduct syndrome[11], and vestibular schwannoma[12,13] are highlighted, whereas among central vestibular diseases, vestibular migraine[14], Parkinson's disease[15], central ischemic lesions[16-18], and motor myelopathies[19-25] stand out.

The VEMP can be generated through auditory or galvanic stimulation and evoked responses can be obtained from several muscles such as extraocular, cervical, masseter, intercostal, brachialis, soleus, or gastrocnemius. The basic principle is the action of the muscular response in the postural control, either through vestibulo-ocular, vestibulocollic, or vestibulospinal reflex[2,3]. With this approach, VEMP application varies according to the type of stimulation and the electromyographic muscular response[2,5]. In its several modalities, this test presents characteristics favorable to its use in clinical practice: objectivity, non-invasiveness, easy execution, low cost, rapidity, and minimal discomfort for the patient. As any other electrophysiological examination, the examiner's experience is a determining factor for the test reliability[2].

## PURPOSE

This study aimed at revising the scientific literature addressing the main techniques used to generate vestibular-evoked myogenic potentials (VEMP) and their clinical applications.

## RESEARCH STRATEGY

A systematic review of the literature was conducted, without meta-analysis, based on the following question: What are the different methods used to generate VEMP and their clinical applications? A search was conducted in the PubMed, Web of Science, MEDLINE, Scopus, LILACS, and SciELO electronic databases for articles published between January 2012 and May 2018. The following descriptors were used in the search: *Vestibular-evoked myogenic potential*, *auditory stimulation*, *electric stimulation*, *postural balance*, and *vestibular nuclei*. Keywords were selected based on consultation with the Health Sciences Descriptors (DeCS) and Medical Subject Headings (MeSH), and were combined using the Boolean operator *AND*. The following combinations were used: *Vestibular-evoked myogenic potential* AND *auditory stimulation*; *Vestibular-evoked myogenic potential* AND *electric stimulation*; *Vestibular-evoked myogenic potential* AND *postural balance; Vestibular-evoked myogenic potential* AND *vestibular nuclei*.

Through these search strategies, 396 publications were found (205 in PubMed, 96 in Web of Science, 35 in MEDLINE, 52 in Scopus, and eight in SciELO). No publications were found on the LILACS database. First, the article titles were analyzed, and those associated with the theme proposed for the review were selected. Titles should make reference to VEMP. A second selection was conducted by analyzing the abstracts, which should include the clinical application of VEMP.

## SELECTION CRITERIA

The articles met the following criteria to be included in this revision: 1) be published in Portuguese, English, or Spanish between January 2012 and May 2018; 2) titles should contain the word VEMP and a clinical application should be described in the title or abstract.

Articles that did not address VEMP and their clinical application in the title or abstract, did not mention the characteristics of the VEMP used, and did not describe the results of the evaluation were excluded. Articles repeated in the databases, literature reviews, case reports, letters, and editorials were also excluded from the review.

After analysis, 28 articles that met the inclusion criteria were selected for review. The article selection process was based on the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA Statement[26] (Figure 1).

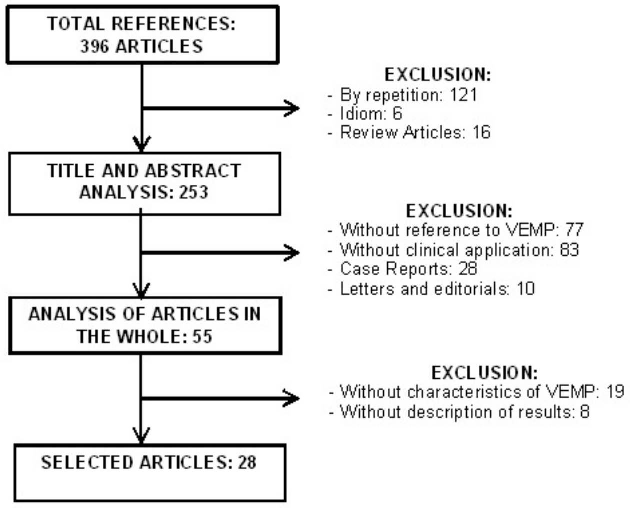


**Figure 1.** Summary of the study selection criteria
**Subtitle:** VEMP = Vestibular-evoked myogenic potential

## DATA ANALYSIS

Initially, the studies were analyzed through the reading of their titles and abstracts. Subsequently, the studies included in the review were read in full. The recommendations included in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE statement)[27] were followed to analyze the selected studies. The following data were extracted from the articles after analysis: authors, year of publication, country where the research was conducted, VEMP recording method, method characterization, recording parameters, sample size, clinical application, and results.

A descriptive analysis of the results was performed and, due to the heterogeneity of the data, it was not possible to perform a meta-analysis.

## RESULTS

The Chart 1 presents a summary of the 28 studies included in this review. The variables country of origin and design were described to assist with characterization of the studies included in the review, but are not part of the main outcomes. All articles selected were published in English. The countries with the largest number of publications were the USA (5; 18%)[8,10,16,18,28] and

**Chart 1.** Characterization of the 28 studies included in the review

| Authors | Year / Country | Design | Sample | VEMP recording method | Method characterization | Application |
|---|---|---|---|---|---|---|
| Chang et al.[5] | 2017 / Taipei (Taiwan) | Cross-sectional descriptive | 70 individuals with unilateral Meniere's disease | VEMP cervical and ocular | Galvanic stimulation on the sternocleidomastoid muscle at 5 mA intensity, air-conducted sound stimulation (at 105 dB nHL intensity), and bone-conducted vibration (at 142 dB intensity), click at 600 Hz frequency | Use of cervical and ocular VEMP to investigate vestibular function in patients with Meniere's disease |
| Lin et al.[6] | 2013 / Taipei (Taiwan) | Cross-sectional descriptive | 50 individuals with unilateral Meniere's disease | VEMP cervical and ocular | Bone-conducted tone burst auditory stimulation at 500 Hz frequency and 144 dB intensity | Use of cervical and ocular VEMP to investigate the relationship with body balance in individuals with Meniere's disease |
| Walther and Blödow[7] | 2013 / Mannheim (Germany) | Cross-sectional comparative | 20 individuals with acute unilateral vestibular neuritis and a control group | VEMP cervical and ocular | Air-conducted tone burst sound stimulation at 500 Hz frequency and 100 dB nHL intensity | Assessment of cervical and ocular VEMP in patients with vestibular neuritis to verify the involvement of the semicircular canals and the otolith organs |
| Janky et al.[8] | 2014 / Baltimore (USA) | Cross-sectional comparative | 16 individuals with SSCD and a control group | VEMP cervical and ocular | Air-conducted sound stimulation, click (at 105 dB nHL intensity) and tone burst (at 125 dB SPL intensity), at 500 Hz frequency | Use of cervical and ocular VEMP in patients with SSCD to evaluate intralabyrinthine pressure |
| Manzari et al.[9] | 2013 / Cassino (Italy) | Cross-sectional comparative | 22 individuals with SSCD and a control group | VEMP cervical and ocular | Air-conducted sound stimulation (at 120 dB SPL intensity) and bone-conducted auditory stimulation (at 130 dB FL intensity), tone burst, at 125-8000 Hz frequency | Use of cervical and ocular VEMP to assist with diagnosis of SSCD |
| Zuniga et al.[10] | 2013 / Baltimore (USA) | Cross-sectional comparative | 29 individuals with SSCD and a control group | VEMP cervical and ocular | Air-conducted sound stimulation, click, at 500 Hz frequency and 105 dB nHL intensity | Use of cervical and ocular VEMP to evaluate sensitivity and specificity in the diagnosis of SSCD |
| Mahdi et al.[12] | 2013 / Tehran (Iran) | Cross-sectional comparative | 10 subjects with vestibular schwannoma and a control group | VEMP cervical | Air-conducted sound stimulation (at 95 dBnHL intensity) and bone-conducted auditory stimulation (at 70 dBnHL intensity), tone burst, at 500 Hz frequency | Use of cervical VEMP to evaluate vestibular function in patients with vestibular schwannoma |

**Subtitle:** VEMP = Vestibular-evoked myogenic potential; BPPV = Benign paroxysmal positional vertigo; SSCD = Superior semicircular canal dehiscence

**Chart 1.** Continued...

| Authors | Year / Country | Design | Sample | VEMP recording method | Method characterization | Application |
|---|---|---|---|---|---|---|
| Chiarovano et al.[13] | 2014 / Paris (France) | Cross-sectional comparative | 83 subjects with vestibular schwannoma and a control group | VEMP cervical and ocular | Air-conducted sound stimulation, click (at 105 dB nHL intensity) and tone burst (at 128 dB SPL intensity) and bone-conducted auditory stimulation, tone burst (at 135 dB intensity), at 500 Hz frequency | Use of cervical and ocular VEMP to assess the vestibular nerve function in patients with vestibular schwannoma |
| Kim et al.[14] | 2015 / Gangwon-do (South Korea) | Cross-sectional comparative | 38 individuals with migraine without aura, 30 individuals with tension headache, and a control group | VEMP cervical and ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 125-130 dB nHL intensity | Use of cervical and ocular VEMP to investigate vestibular function in patients with migraine and tension headache |
| Shalash et al.[15] | 2017 / Cairo (Egypt) | Cross-sectional comparative | 15 individuals with Parkinson's disease and a control group | VEMP cervical and ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 90 dBnHL intensity | Use of cervical and ocular VEMP to evaluate motor and non-motor symptoms in individuals with Parkinson's disease |
| Miller et al.[16] | 2014 / Chicago (USA) | Cross-sectional descriptive | 17 individuals with post-stroke spastic hypertonia | VEMP cervical | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 95 dB nHL intensity | Use of cervical VEMP to evaluate the level of spasticity in patients with post-stroke spasticity |
| Oh et al.[17] | 2013 / Jeonju (South Korea) | Cross-sectional descriptive | 52 individuals with acute brain injury | VEMP ocular | Air-conducted sound stimulation, tone burst, at 1000 Hz frequency and 100 dB nHL intensity | Use of ocular VEMP to evaluate the otolith ocular function involved in acute brain lesions |
| Miller et al.[18] | 2016 / Pittsburgh (USA) | Cross-sectional descriptive | 19 post-stroke individuals | VEMP ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 95 dB nHL intensity | Assessment of ocular VEMP to analyze the ascending vestibulo-ocular pathways in post-stroke patients |
| Squair et al.[19] | 2016 / Vancouver (Canada) | Cross-sectional comparative | 16 individuals with spinal cord injury and a control group | VEMP cervical and soleus | Galvanic stimulation on the sternocleidomastoid muscle at 2 mA intensity and air-conducted sound stimulation, tone burst, at 500 Hz frequency and 125 dB intensity. | Use of cervical and soleus VEMP to evaluate muscle activity in individuals with spinal cord injury |
| Caporali et al.[20] | 2016 / Belo Horizonte (Brazil) | Cross-sectional comparative | 22 individuals with schistosomal myeloradiculopathy and control group | VEMP soleus | Galvanic stimulation on the sternocleidomastoid muscle at 2 mA intensity | Use of soleus VEMP to assess spinal cord function in individuals with schistosomal myeloradiculopathy |
| Felipe et al.[21] | 2013 / Belo Horizonte (Brazil) | Cross-sectional comparative | 60 individuals infected with Human T-lymphotropic virus type 1 (HTLV-1) and a control group | VEMP cervical | Air-conducted sound stimulation, tone burst, at 1000 Hz frequency and 118 dB HL intensity | Use of cervical VEMP to investigate subclinical neurological changes associated with HTLV-1 infection |
| Pelosi et al.[28] | 2013 / Nashville (USA) | Cross-sectional descriptive | 31 individuals with isolated unilateral utricular dysfunction | VEMP ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 95 dB HL intensity | Use of ocular VEMP to define the characteristics of isolated unilateral utricular dysfunction |

**Subtitle:** VEMP = Vestibular-evoked myogenic potential; BPPV = Benign paroxysmal positional vertigo; SSCD = Superior semicircular canal dehiscence

**Chart 1.** Continued...

| Authors | Year / Country | Design | Sample | VEMP recording method | Method characterization | Application |
|---|---|---|---|---|---|---|
| Silva et al.[29] | 2017 / Belo Horizonte (Brazil) | Cross-sectional comparative | 30 individuals with unilateral Meniere's disease, 30 individuals with vestibular hyporeflexia, and a control group | VEMP cervical and ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 120 dBnHL intensity | Use of cervical and ocular VEMP to assess vestibular function in patients with Meniere's disease and vestibular hyporeflexia |
| Saka et al.[30] | 2012 / Nishinomiya (Japan) | Cross-sectional descriptive | 25 individuals with otosclerosis | VEMP cervical | Bone-conducted auditory stimulation, tone burst, at de 250 Hz frequency and 60 dB nHL intensity | Use of cervical VEMP to evaluate balance in individuals with otosclerosis |
| Tal et al.[31] | 2016 / Haifa (Israel) | Cross-sectional descriptive | 30 sailors on medication for motion sickness | VEMP cervical | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 90 dB nHL intensity | Use of cervical VEMP to assess absorption and efficacy of motion sickness medication |
| Brantberg and Verrecchia[32] | 2012 / Stockholm (Sweden) | Cross-sectional comparative | 38 individuals with SSCD and a control group | VEMP cervical | Air-conducted sound stimulation, click (at 80-90 dB nHL intensity) and tone burst (at 130 dB SPL intensity), at 500 Hz frequency | Use of cervical VEMP as a screening test in patients with SSCD |
| Demirhan et al.[33] | 2016 / Istanbul (Turkey) | Cross-sectional comparative | 30 individuals with cochlear implant and a control group | VEMP cervical | Air-conducted sound stimulation, tone burst, at 500 and 1000 Hz frequencies and 100 dB nHL intensity | Use of cervical VEMP in individuals with cochlear implant to assess vestibular function |
| Tax et al.[34] | 2013 / Sidney (Australia) | Cross-sectional comparative | Eight individuals with bilateral vestibular dysfunction and a control group | VEMP cervical, ocular, and soleus | Galvanic stimulation at 1 mA intensity | Evaluation of VEMP with galvanic stimulation to analyze the vestibulospinal reflex in individuals with bilateral vestibular dysfunction |
| Sreenivasan et al.[35] | 2015 / Puducherry (India) | Cross-sectional comparative | 15 individuals with BPPV and a control group | VEMP cervical | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 105 dB nHL intensity | Assessment of cervical VEMP to define the characteristics of BPPV |
| Güven et al.[36] | 2014/ Cankaya (Turkey) | Cross-sectional comparative | 50 individuals with multiple sclerosis and a control group | VEMP cervical | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 120 dB intensity | Use of cervical VEMP to evaluate the contribution of this myogenic potential to the diagnosis of multiple sclerosis |
| Harirchian et al.[37] | 2013 / Tehran (Iran) | Cross-sectional comparative | 20 individuals with multiple sclerosis and a control group | VEMP cervical | Air-conducted sound stimulation, click, at 500 Hz frequency and 95 dB NHL intensity | Use of cervical VEMP to assess sensitivity in the diagnosis of multiple sclerosis |
| Iwasaki et al.[38] | 2013 / Tokyo (Japan) | Cross-sectional comparative | 14 individuals with unilateral peripheral vestibular dysfunction and a control group | VEMP ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 135 dBSPL intensity | Use of ocular VEMP to investigate vestibular function in individuals with vestibular dysfunction |
| Parkes et al.[39] | 2017 / Toronto (Canada) | Longitudinal cohort | 33 individuals with cochlear implant assessed by VEMP and a non-exposed group | VEMP cervical and ocular | Air-conducted sound stimulation, tone burst, at 500 Hz frequency and 124 dB SPL intensity | Use of cervical and ocular VEMP in individuals with cochlear implant |

**Subtitle:** VEMP = Vestibular-evoked myogenic potential; BPPV = Benign paroxysmal positional vertigo; SSCD = Superior semicircular canal dehiscence

Brazil (3; 11%)[20,21,29]. Sample size of the studies ranged from eight to 83 individuals with peripheral and central vestibular disorders.

Regarding the design, eight (29%) studies were descriptive[5-6,16-18,28,30-31],19 (68%) were comparative cross-sectional[7-10,12-15,19-21,29,32-38], and one (3%) was longitudinal cohort[39].

With respect to the diseases, the most commonly investigated clinical applications in patients with vestibular disorders referred to Meniere's disease[5-6,29], superior semicircular canal dehiscence syndrome[8-10,32], vestibular schwannoma[12-13], and central ischemic lesions[15-21,36-37].

Three methods of vestibular-evoked myogenic potential (VEMP) recording were identified in the 28 articles assessed, with the cervical and the ocular as the most commonly used methods (Figure 2).

Concerning the type of applied stimulation, the number (%) of studies using the sound or the electric stimulation were: 19 (68%), auditory - rarefaction tone burst[6-7,9,12,14-18,21,28-31,33,35-36,38-39]; three (11%), auditory - rarefaction tone burst and click[8,13,32]; two (7%), auditory - click[10,37]; two (7%), galvanic[20,34]; one (3.5%), auditory - click and galvanic[5]; one (3.5%), auditory - rarefaction tone burst and galvanic[19]. The electric current intensity of galvanic stimulation ranged from 1 to 5 mA[5,19,20,34].

Regarding the frequency of auditory stimulation, 500 Hz was predominant - used in 21 (81%) studies[6-8,10,12-16,18-19,28-29,31-33,35-39], followed by 1000 Hz - applied in two (7%) investigations[17,21], 600 Hz - used in one (4%) survey[5], 250 Hz - utilized in one (4%) study[30], and one research used various frequencies[9].

Regarding the type of stimulus conduction, 21 (81%) studies used air-conducted sound[7-10,14-19,21,28-29,31-33,35-39], two (7%) researches applied bone-conducted vibration[6,30], and three (12%) surveys utilized both air- and bone-conducted stimulation[5,12,13] .

All the studies that used VEMP to evaluate Meniere's disease[5-6,29] adopted either cervical or ocular recording. About the type of stimulus, two of these surveys[6,29] used rarefaction tone burst auditory stimulation at a frequency of 500 Hz and one[5] applied click auditory stimulation at 600 Hz. Air-conducted sound[29], bone-conducted vibration[6], and both air- and bone-conducted stimulation[5] were also observed.

With respect to application of VEMP to superior semicircular canal dehiscence[8-10,32], this review verified that three studies[8-10] used cervical and ocular VEMP recording and one used only cervical recording. Of these studies, one[9] applied rarefaction tone burst auditory stimulation at variable frequency, one[10] used click auditory stimulation at 500 Hz, and two[8,32] utilized both rarefaction tone burst and click auditory stimulation at a frequency of 500 Hz. The air-conducted sound stimulation was the only chosen in all the studies[8-10,32].

As for application to vestibular schwannoma[12,13], one study[13] used cervical and ocular VEMP recording and the other[12] used only cervical recording. One[12] utilized air-conducted rarefaction tone burst sound stimulation at a frequency of 500 Hz and the other[13] applied both air-conducted sound and bone-conducted vibration stimulation using rarefaction tone burst and click at 500 Hz.

About VEMP for testing central ischemic lesions[15-21,36,37], this review found that one study[15] used both cervical and ocular VEMP, four[16,21,36,37] used only cervical VEMP, two[17,18] only ocular VEMP, one[20] only soleus VEMP, and one[19] applied both cervical and soleus VEMP. Of these studies, four[15-16,18,36] used air-conducted rarefaction tone burst sound stimulation at a frequency of 500 Hz, two[17,21] applied air-conducted rarefaction tone burst sound stimulation at 1000 Hz, one[37] utilized air-conducted click sound stimulation at 500 Hz, one[19] used air-conducted rarefaction tone burst sound stimulation at 500 Hz and galvanic stimulation at an electric current of 2 mA, and one[20] applied only galvanic stimulation at 2 mA.

The Chart 2 shows a summary of the main characteristics of the VEMP recording methods. Figures 3, 4, and 5 show VEMP recording methods according to the type of stimulation and neural pathway, positioning of the electrodes for muscle response, and electrophysiological waveform generated.

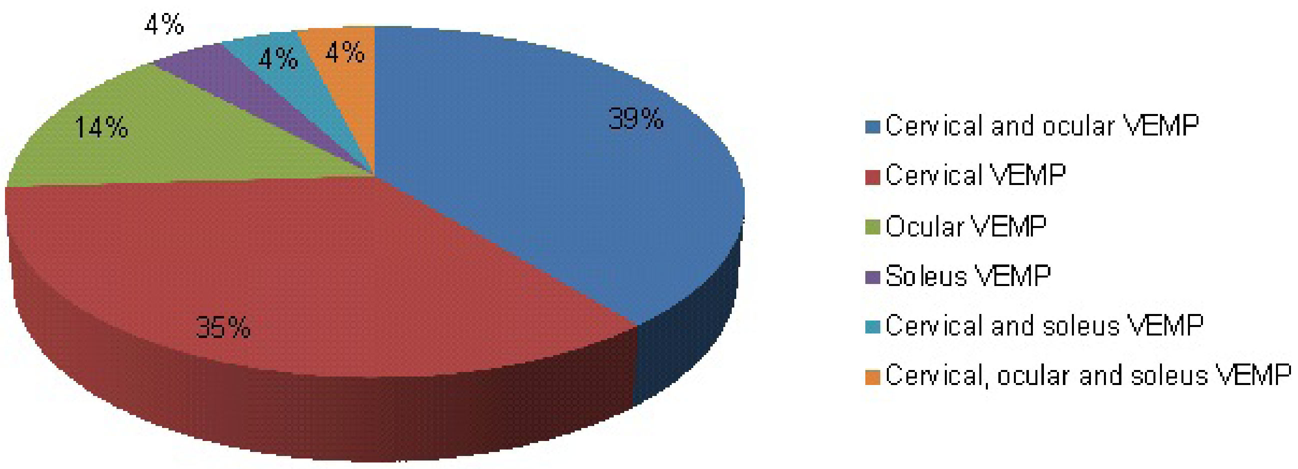


**Figure 2.** Distribution of the studies according to the methods of vestibular myogenic evoked potential (VEMP) recording
**Subtitle:** VEMP = Vestibular-evoked myogenic potential

**Chart 2.** Summary of the main characteristics of the vestibular-evoked myogenic potential (VEMP) recording methods

| Types of VEMP | Ocular VEMP | Cervical VEMP | Soleus VEMP |
|---|---|---|---|
| Record of the response muscle | Extraocular, mainly inferior oblique | Sternocleidomastoid | Soleus or Gastrocnemius |
| Stimulation more used | Auditory (sound) | Auditory (sound) | Galvanic (electric) |
| Neural pathway assessed | Contralateral vestibulo-ocular tract | Medial vestibulospinal tract (ipsilateral via) | Lateral vestibulospinal tract (ipsilateral via) |
| Biphasic electrophysiological waveform | N10 - P15 | P13 - N23 | SL – ML |

**Subtitle:** VEMP = Vestibular-evoked myogenic potential; N10 = Negative peak N with mean latency of 10 ms; P15 = Positive peak P with mean latency of 15 ms; P13 = Positive peak P with mean latency of 13 ms; N23 = Negative peak N with mean latency of 23 ms; SL = Short-latency component (approximately 60 ms); ML = Medium-latency component (approximately 110 ms)

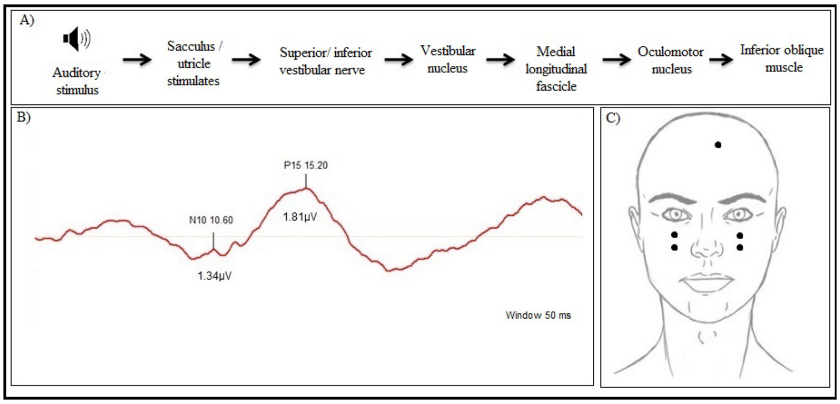


**Figure 3.** Ocular vestibular-evoked myogenic potential (ocular VEMP). (A) Type of stimulation and neural pathway; (B) Electrophysiological waveform; (C) Positioning of the electrodes for recording

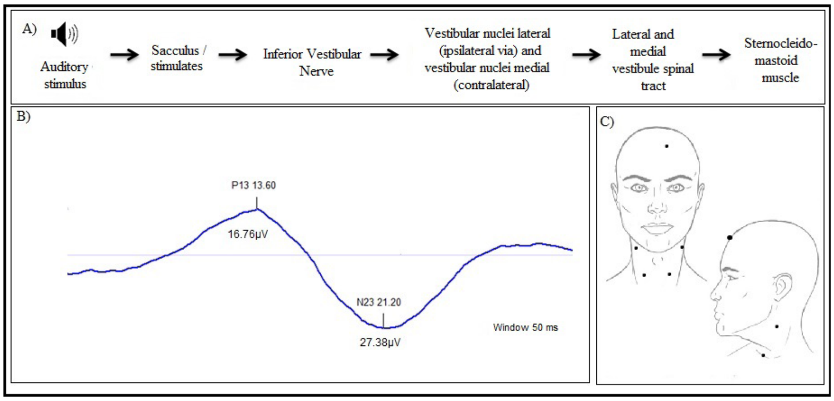


**Figure 4.** Cervical vestibular-evoked myogenic potential (cervical VEMP). (A) Type of stimulation and neural pathway; (B) Electrophysiological waveform; (C) Positioning of the electrodes for recording

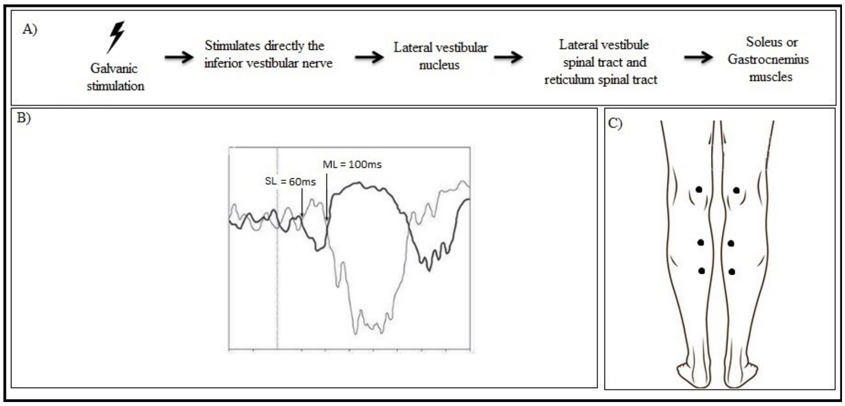


**Figure 5.** Soleus muscle vestibular-evoked myogenic potential (soleus VEMP). (A) Type of stimulation and neural pathway; (B) Electrophysiological waveform; (C) Positioning of the electrodes for recording

## DISCUSSION

The studies about VEMP with auditory stimulation have evidenced this test as an assisting tool for the diagnosis of several types of peripheral vestibular disorders, predominantly Meniere's disease[5,6,29,40] and superior semicircular canal dehiscence (SSCD)[8-11,32], as well as diseases related to central vestibular disorders, such as motor myelopathies[19-25] and Parkinson's disease[15,41-43].

In Meniere's disease, some authors have reported that cervical VEMP changes occur in consequence of the cochleosaccular hydrops[5,6], while other authors have understood that the changes depend on the stage of this disease[29,40]. In the early stages of the disease, increased amplitudes are observed in cervical VEMP owing to hypersensitivity of the saccule, which would be caused by saccular dilatation, whereas in late stages, the amplitudes may be attenuated as a result of atrophy of the sensory epithelium of the saccular membrane[29]. Concomitant changes in cervical and ocular VEMP would be associated with involvement of the saccule and the utricle, respectively[5,40]. Therefore, simultaneous alteration of cervical and ocular VEMP occurs more commonly in the advanced stage of Meniere's disease[29,40].

The literature reports that, in SSCD, the cervical and the ocular VEMP recording presents a pattern of response that is different from those observed in other vestibular diseases[8-10]. Electrophysiological response with auditory stimulation at lower sound intensity (approximately 70 dB nHL) is observed, as well as waveforms with increased amplitude on the compromised side, keeping the normal morphology[11,32]. This finding has been associated with a change in the bone layer that covers the superior semicircular canal[8-10] that when thinner, can cause a decrease in impedance and, consequently, an increased sound transmission to the labyrinth, with greater sensitivity of the saccule to sound stimulation. VEMP response at low sound stimulation associated with higher wave amplitude that increases according to the level of sound intensity for both the cervical and the ocular potentials, suggest the diagnosis of SSCD and indicate that the central vestibular system is not affected in this syndrome[8-11,32].

Regarding central lesions, studies addressing infectious myelopathies showed that cervical VEMP responses were altered in over half of the individuals with myelopathy[22-23]. Cervical VEMP enabled to diagnose a spinal disfunction that was subclinical, in addition to assessing the disease evolution[21].

In Parkinson's disease, cervical VEMP and ocular VEMP were used to evaluate the postural control. A study that assessed the vestibulocollic reflex in individuals with Parkinson's disease reported that cervical VEMP responses showed reduced amplitudes. According to the authors, these findings suggest reduction in the reflexes that correlate with the vestibular activity[15]. Another study showed changes in cervical and ocular VEMP responses in patients with Parkinson's disease and postural instability[43].

About the type of sound stimulus used to generate VEMP, the tone burst auditory stimulation was identified in several studies and it is justified by the fact that the threshold of saccular excitability is lower for this type of stimulus when compared to click stimulation, and it is more comfortable for the individual[4]. The frequency of 500 Hz is the most common choice because it generates a more homogeneous and constant response[4,44].

With respect to the comparison of air-conducted sound and bone-conducted vibration auditory stimulation, some authors believe that the advantage of the latter lies in the possibility of testing individuals with conductive hearing loss[7,12,17,30]. However, bone-conducted stimulation is seldom used, considering that galvanic stimulation, which is independent of the middle ear, offers more robust electrophysiological response[42,45,46].

Studies have observed that VEMP obtained through galvanic stimulation presents the advantage of acting on the postsynaptic membrane, next to the vestibular nuclei and, when associated with other vestibular battery tests, enables distinction between peripheral and central vestibular disorders[45,46]. As galvanic stimulation reaches the terminal axons of the vestibular nerve in the junction with the vestibular nucleus, when comparing the response to VEMP using auditory stimulation with that of VEMP using galvanic stimulation in the same patient, it is possible to differentiate whether the lesion is vestibular or retrovestibular[42,45-47]. For example, in the presence of peripheral vestibular neuropathy, VEMP with auditory stimulation will show altered results, whereas VEMP with galvanic stimulation will present normal result[25].

VEMP with galvanic stimulation has been proved to be an important tool for the subclinical diagnosis of motor myelopathies[20,21,25] and for the definition of the level of spinal cord involvement[19-21]. For instance, when assessing patients with motor or traumatic myelopathy and submitting them to VEMP with galvanic stimulation with the response recorded in different postural muscles (e.g. cervical, intercostal, and soleus), it is possible to infer about the topodiagnosis of the medullar lesion based on which muscle presented VEMP response. In clinical practice, recording of soleus VEMP triggered by auditory stimulation is difficult to obtain due to lower accumulation of energy, compared with that of the galvanic method, which is much more robust[46]. Thus, for the VEMP of the soleus muscle, the best stimulus is the galvanic one. For ocular and cervical VEMP, the response can be generated with both auditory and galvanic stimuli.

The different methods related to the parameters used to perform VEMP and the presentation of the results limited the comparison among studies. On the other hand, the importance of using different VEMP recording methods to assess otolith function and vestibular pathway is the diversity of vestibular diseases that can be evaluated through VEMP. Therefore, in vestibular electrophysiology research, VEMP has emerged as an outstanding complementary examination to assess vestibular function. The use of VEMP, coupled with other vestibular tests, enables a more comprehensive evaluation and, consequently, a better knowledge about the structures contained in the labyrinth and their neural pathways.

## CONCLUSION

In this article, we reviewed the clinical aspects of VEMP, the stimulus modalities and the muscles most used to register the evoked response. Cervical VEMP, ocular VEMP and soleus VEMP are the most used. The auditory stimulus is the most used to generate the cervical and ocular VEMP, while the galvanic (electric) stimulus is the most used to generate the VEMP of the soleus muscle. These tests are very important for the evaluation of peripheral and central vestibular system function.

## REFERENCES


1. Silva TR, Resende LM, Santos MAR. Potencial evocado miogênico vestibular ocular e cervical simultâneo em indivíduos normais. CoDAS. 2016;28(1):34-40. http://dx.doi.org/10.1590/2317-1782/20162015040. PMid:27074187.
2. Kantner C, Gürkov R. Characteristics and clinical applications of ocular vestibular evoked myogenic potentials. Hear Res. 2012;294(1-2):55-63. http://dx.doi.org/10.1016/j.heares.2012.10.008. PMid:23123220.
3. Cunha LCM, Labanca L, Tavares MC, Gonçalves DU. Vestibular evoked myogenic potential (VEMP) with galvanic stimulation in normal subjects. Braz J Otorhinolaryngol. 2014;80(1):48-53. http://dx.doi.org/10.5935/1808-8694.20140011. PMid:24626892.
4. Park HJ, Lee IS, Shin JE, Lee YJ, Park MS. Frequency-tuning characteristics of cervical and ocular vestibular evoked myogenic potentials induced by air-conducted tone bursts. Clin Neurophysiol. 2010;121(1):85-9. http://dx.doi.org/10.1016/j.clinph.2009.10.003. PMid:19892592.
5. Chang CM, Young YH, Jaw FS, Wang CT, Cheng PW. Degeneration of the vestibular nerve in unilateral Meniere's disease evaluated by galvanic vestibular-evoked myogenic potentials. Clin Neurophysiol. 2017;128(9):1617-24. http://dx.doi.org/10.1016/j.clinph.2017.06.004. PMid:28719825.
6. Lin CY, Wang SJ, Young YH. Correlations between foam posturography and vestibular-evoked myogenic potential tests in Ménière's disease. Ear Hear. 2013;34(5):673-9. http://dx.doi.org/10.1097/AUD.0b013e31828d267f. PMid:23985977.
7. Walther LE, Blödow A. Ocular vestibular evoked myogenic potential to air conducted sound stimulation and video head impulse test in acute vestibular neuritis. Otol Neurotol. 2013;34(6):1084-9. http://dx.doi.org/10.1097/MAO.0b013e318280da47. PMid:23370570.
8. Janky KL, Zuniga MG, Schubert MC, Carey JP. The effect of increased intracranial pressure on vestibular evoked myogenic potentials in superior canal dehiscence syndrome. Clin Neurophysiol. 2015;126(4):780-6. http://dx.doi.org/10.1016/j.clinph.2014.06.049. PMid:25103787.
9. Manzari L, Burgess AM, McGarvie LA, Curthoys IS. An indicator of probable semicircular canal dehiscence: ocular vestibular evoked myogenic potentials to high frequencies. Otolaryngol Head Neck Surg. 2013;149(1):142-5. http://dx.doi.org/10.1177/0194599813489494. PMid:23674567.
10. Zuniga MG, Janky KL, Nguyen KD, Welgampola MS, Carey JP. Ocular versus cervical VEMPs in the diagnosis of superior semicircular canal dehiscence syndrome. Otol Neurotol. 2013;34(1):121-6. http://dx.doi.org/10.1097/MAO.0b013e31827136b0. PMid:23183641.
11. Janky KL, Nguyen KD, Welgampola M, Zuniga MG, Carey JP. Air-conducted oVEMPs provide the best separation between intact and superior canal dehiscent labyrinths. Otol Neurotol. 2013;34(1):127-34. http://dx.doi.org/10.1097/MAO.0b013e318271c32a. PMid:23151775.
12. Mahdi P, Amali A, Pourbakht A, Yazdi AK, Bassam A. Vestibular evoked myogenic potential produced by bone-conducted stimuli: a study on its basics and clinical applications in patients with conductive and sensorineural hearing loss and a group with vestibular Schawannoma. Iran J Otorhinolaryngol. 2013;25(72):141-6. PMid:24303434.
13. Chiarovano E, Darlington C, Vidal PP, Lamas G, de Waele C. The role of cervical and ocular vestibular evoked myogenic potentials in the assessment of patients with vestibular schwannomas. PLoS One. 2014;9(8):1-10. http://dx.doi.org/10.1371/journal.pone.0105026. PMid:25137289.
14. Kim CH, Jang MU, Choi HC, Sohn JH. Subclinical vestibular dysfunction in migraine patients: a preliminary study of ocular and rectified cervical vestibular evoked myogenic potentials. J Headache Pain. 2015;16(1):1-9. http://dx.doi.org/10.1186/s10194-015-0578-5. PMid:26527349.
15. Shalash AS, Hassan DM, Elrassas HH, Salama MM, Méndez-Hernández E, Salas-Pacheco JM, et al. Auditory – and vestibular – evoked potentials correlate with motor and non-motor features of Parkinson's disease. Front Neurol. 2017;8:1-8. http://dx.doi.org/10.3389/fneur.2017.00055. PMid:28289399.
16. Miller DM, Klein CS, Suresh NL, Rymer WZ. Asymmetries in vestibular evoked myogenic potentials in chronic stroke survivors with spastic hypertonia: evidence for a vestibulospinal role. Clin Neurophysiol. 2014;125(10):2070-8. http://dx.doi.org/10.1016/j.clinph.2014.01.035. PMid:24680197.
17. Oh SY, Kim JS, Lee JM, Shin BS, Hwang SB, Kwak KC, Kim C, Jeong SK, Kim TW. Ocular vestibular evoked myogenic potentials induced by air-conducted sound in patients with acute brainstem lesions. Clin Neurophysiol. 2013;124(4):770-8. http://dx.doi.org/10.1016/j.clinph.2012.09.026. PMid:23121898.
18. Miller DM, Baker JF, Rymer WZ. Ascending vestibular drive is asymmetrically distributed to the inferior oblique motoneuron pools in a subset of hemispheric stroke survivors. Clin Neurophysiol. 2016;127(4):2022-30. http://dx.doi.org/10.1016/j.clinph.2016.01.019. PMid:26971485.
19. Squair JW, Bjerkefors A, Inglis JT, Lam T, Carpenter MG. Cortical and vestibular stimulation reveal preserved descending motor pathways in individuals with motor-complete spinal cord injury. J Rehabil Med. 2016;48(7):589-96. http://dx.doi.org/10.2340/16501977-2101. PMid:27292455.
20. Caporali JFM, Gonçalves DU, Labanca L, Oliveira LD, Trindade GVM, Pereira TA, et al. Vestibular evoked myogenic potential (VEMP) triggered by galvanic vestibular stimulation (GVS): a promising tool to assess spinal cord function in Schistosomal Myeloradiculopathy. PLoS Negl Trop Dis. 2016;10:1-11.
21. Felipe L, Kingma H, Lambertucci JR, Carneiro-Proietti AB, Gonçalves DU. Testing the vestibular evoked myogenic potential (VEMP) to identify subclinical neurological alterations in different phases of human T-lymphotropic virus type 1 infection. Spine J. 2013;13(4):397-401. http://dx.doi.org/10.1016/j.spinee.2012.11.015. PMid:23267739.
22. Felipe L, Gonçalves DU, Santos MA, Proietti FA, Ribas JG, Carneiro-Proietti AB, Lambertucci JR. Vestibular-Evoked Myogenic Potential (VEMP) to Evaluate Cervical Myelopathy in Human T-Cell Lymphotropic Virus Type I Infection. Spine. 2008;33(11):1180-4. http://dx.doi.org/10.1097/BRS.0b013e31817152ed. PMid:18469690.
23. Labanca L, Starling AL, Sousa-Pereira SR, Romanelli LC, Carneiro-Proietti ABF, Carvalho LN, et al. Electrophysiological analysis shows dizziness as the first symptom in Human T Cell Lymphotropic Virus Type-Associated Myelopathy/Tropical Spastic Paraparesis. AIDS Res Hum Retroviruses. 2015;31(6):649-54. http://dx.doi.org/10.1089/aid.2014.0153. PMid:25760424.
24. Iles JF, Baderin R, Tanner R, Simon A. Human standing and walking: comparison of the efects of stimulation of the vestibular system. Exp Brain Res. 2007;178(2):151-66. http://dx.doi.org/10.1007/s00221-006-0721-2. PMid:17031681.
25. Cunha LCM, Tavares MC, Criollo CJT, Labanca L, Paz CCSC, Martins HR, et al. Contribution of galvanic vestibular stimulation in the diagnosis of HTLV-1-associated myelopathy/tropical spastic paraparesis. J Clin Neurol. 2013;9(4):252-8. http://dx.doi.org/10.3988/jcn.2013.9.4.252. PMid:24285967.

26. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. PLoS Med. 2009;6(7):e1000097. http://dx.doi.org/10.1371/journal.pmed.1000097. PMid:19621072.

27. Malta M, Cardoso LO, Bastos FI, Magnanini MM, Silva CM. Iniciativa STROBE: subsídios para a comunicação de estudos observacionais. Rev Saude Publica. 2010;44(3):559-65. http://dx.doi.org/10.1590/S0034-89102010000300021. PMid:20549022.

28. Pelosi S, Schuster D, Jacobson GP, Carlson ML, Haynes DS, Bennett ML, et al. Clinical characteristics associated with isolated unilateral utricular dysfunction. Am J Otolaryngol. 2013;34(5):490-5. http://dx.doi.org/10.1016/j.amjoto.2013.04.008. PMid:23759133.

29. Silva TR, Resende LM, Santos MAR. Combined ocular and cervical vestibular evoked myogenic potential in individuals with vestibular hyporeflexia and in patients with Ménière's disease. Rev Bras Otorrinolaringol (Engl Ed). 2017;83(3):330-40. http://dx.doi.org/10.1016/j.bjorl.2016.04.017. PMid:27320652.

30. Saka N, Seo T, Fujimori K, Mishiro Y, Sakagami M. Vestibular-evoked myogenic potential in response to bone-conducted sound in patients with otosclerosis. Acta Otolaryngol. 2012;132(11):1155-9. http://dx.doi.org/10.3109/00016489.2012.694473. PMid:22830649.

31. Tal D, Shemy S, Kaminski-Graif G, Wiener G, Hershkovitz D. Vestibular evoked myogenic potentials and motion sickness medications. Clin Neurophysiol. 2016;127(6):2350-4. http://dx.doi.org/10.1016/j.clinph.2016.03.010. PMid:27178852.

32. Brantberg K, Verrecchia L. Effectiveness of different click stimuli in diagnosing superior canal dehiscence using cervical vestibular evoked myogenic potentials. Acta Otolaryngol. 2012;132(10):1077-83. http://dx.doi.org/10.3109/00016489.2012.689858. PMid:22779948.

33. Demirhan H, Yıldız M, Yiğit Ö. Do Vestibular-evoked myogenic potential abnormalities in patients with cochlear implant only reflect saccular dysfunction? J Int Adv Otol. 2016;12(2):166-9. http://dx.doi.org/10.5152/iao.2016.2522. PMid:27716603.

34. Tax CMW, Bom AP, Taylor RL, Todd N, Cho K-KJ, Fitzpatrick RC, Welgampola MS, et al. The galvanic whole-body sway response in health and disease. Clin Neurophysiol. 2013;124(10):2036-45. http://dx.doi.org/10.1016/j.clinph.2012.12.041. PMid:23849702.

35. Sreenivasan A, Sivaraman G, Parida PK, Alexander A, Saxena SK, Suria G. The clinical utility of vestibular evoked myogenic potentials in patients of benign paroxysmal positional vertigo. J Clin Diagn Res. 2015;9(6):1-3. PMid:26266140.

36. Güven H, Bayır O, Aytaç E, Ozdek A, Comoğlu SS, Korkmaz H. Vestibular-evoked myogenic potentials, clinical evaluation, and imaging findings in multiple sclerosis. Neurol Sci. 2014;35(2):221-6. http://dx.doi.org/10.1007/s10072-013-1483-9. PMid:23807120.

37. Harirchian MH, Karimi N, Nafisi S, Akrami S, Ghanbarian D, Gharibzadeh S. Vestibular evoked myogenic potential for diagnoses of multiple sclerosis: is it beneficial? Med Glas (Zenica). 2013;10(2):321-6. PMid:23892852.

38. Iwasaki S, Egami N, Inoue A, Kinoshita M, Fujimoto C, Murofushi T, et al. Ocular vestibular evoked myogenic potential elicited from binaural air-conducted stimulations: clinical feasibility in patients with peripheral vestibular dysfunction. Acta Otolaryngol. 2013;133(7):708-13. http://dx.doi.org/10.3109/00016489.2013.767476. PMid:23768055.

39. Parkes WJ, Gnanasegaram JJ, Cushing SL, McKnight CL, Papsin BC, Gordon KA. Vestibular evoked myogenic potential testing as an objective measure of vestibular stimulation with cochlear implants. Laryngoscope. 2017;127(2):E75-81. http://dx.doi.org/10.1002/lary.26037. PMid:27291637.

40. Wen MH, Cheng PW, Young YH. Augmentation of ocular vestibular evoked myogenic potentials via bone-conducted vibration stimuli in Meniere's disease. Otolaryngol Head Neck Surg. 2012;146(5):797-803. http://dx.doi.org/10.1177/0194599811433982. PMid:22237297.

41. Kataoka H, Okada Y, Kiriyama T, Kita Y, Nakamura J, Morioka S, et al. Can postural instability respond to galvanic vestibular stimulation in patients with Parkinson's Disease? J Mov Disord. 2015;9(1):40-3. http://dx.doi.org/10.14802/jmd.15030. PMid:26648182.

42. Samoudi G, Jivegard M, Mulavara AP, Bergquist F. Effects of stochastic vestibular galvanic stimulation and LDOPA on balance and motor symptoms in patients with Parkinson's disease. Brain Stimul. 2015;8(3):474-80. http://dx.doi.org/10.1016/j.brs.2014.11.019. PMid:25573070.

43. Natale ER, Ginatempo F, Paulus KS, Pes GM, Manca A, Tolu E, et al. Abnormalities of vestibular-evoked myogenic potentials in idiopathic Parkinson's disease are associated with clinical evidence of brainstem involvement. Neurol Sci. 2015;36(6):995-1001. http://dx.doi.org/10.1007/s10072-014-2054-4. PMid:25567081.

44. Cheng PW, Huang TW, Young YH. The influence of clicks versus short tone bursts on the vestibular evoked myogenic potentials. Ear Hear. 2003;24(3):195-7. http://dx.doi.org/10.1097/01.AUD.0000069225.80220.CB. PMid:12799540.

45. Carmona S, Ferrero A, Pianetti G, Escolá N, Arteaga MV, Frankel L. Galvanic vestibular stimulation improves the results of vestibular rehabilitation. Ann N Y Acad Sci. 2011;1233(1):1-7. http://dx.doi.org/10.1111/j.1749-6632.2011.06269.x. PMid:22360772.

46. Watson SRD, Colebatch JG. Vestibular-evoked electromyographic responses in soleus: a comparison between click and galvanic stimulation. Exp Brain Res. 1998;119(4):504-10. http://dx.doi.org/10.1007/s002210050366. PMid:9588785.

47. Collard M. The vestibular system: from structure to function. Rev Prat. 1994;44(3):295-8. PMid:8178092.