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# Ocular vestibular evoked myogenic potentials in patients with single sided deafness

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ORIGINAL STUDY

# Ocular vestibular-evoked myogenic potentials in patients with single-sided deafness

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**Abstract**

*Introduction*: **Clinically unilateral severe-to-profound sensorineural hearing loss is known as single-sided deafness (SSD). It is defined by severe-to-profound hearing thresholds with a poor word recognition ability. SSD is not uncommonly encountered in otology, its symptoms are hearing loss and often associated with the vestibular system. In SSD, otolithic dysfunction may be frequently misdiagnosed and the majority of patients were affected by cochlear and superior vestibular nerve and then inferior vestibular nerve. Otolith damage may be present in patients with SSD because it shares a membranous structure, in addition, it has similar receptor cells. The vestibule and cochlea may be impacted by the same detrimental elements from an anatomical perspective.**

*Objective*: **Here, we assess the prevalence of vestibular dysfunction by measuring ocular vestibular-evoked myogenic potential (oVEMP), cervical vestibular-evoked myogenic potential (cVEMP), and caloric findings in patients with SSD.**

*Patients and methods*: **This study had two groups of participants: group A, which consisted of 20 patients with normal hearing sensitivity on both sides, and group B, which consisted of 20 participants with SSD. Two groups, each with an age range of 20−60 years, were free of vestibular symptoms.**

*Results*: **The results showed a statistically significant difference in oVEMP between SSD and control group as increase in latencies of P1 (P10) and N1 (N15) and decrease in amplitude.**

*Conclusion*: **oVEMPs are able to identify vestibular signs in patients with SSD who are asymptomatic and have never complained of vestibular impairment, oVEMPs are able to identify vestibular signs in these patients, and oVEMP test is the most sensitive test and caloric test is most specific for identifying important vestibular signs in these patients.**

*Keywords:* Cervical vestibular-evoked myogenic potential, Ocular vestibular-evoked myogenic potential, Single-sided deafness

## 1. Introduction

Single-sided deafness (SSD), also known as unilateral severe-to-profound sensorineural hearing loss, is characterized by clinically unaidable hearing and poor word identification [1]. SSD is most associated with congenital hearing loss and infectious diseases. SSD can have a variety of etiologies, the most common being idiopathic in nature. Others include cochleovestibular anomalies, temporal bone trauma, Meniere's disease, vestibular schwannoma, vascular ischemia, autoimmune illnesses, and infections. Often, this loss can be sudden in onset, leaving the patient extremely debilitated [2,3]. SSD is defined by severe-to-profound hearing thresholds with a poor word recognition ability [4,5]. In children often with congenital hearing loss is bilateral such as Usher syndrome, meningitis, congenital CMV infection, and enlarged vestibular aqueduct syndrome or acquired in children treated with ototoxic agents. In SSD, vestibular disturbance is often associated with progression of hearing loss and these children may complain with true vertigo [6]. From the anatomical view, the cochlea and the vestibular system share a continuous membranous labyrinth, in addition, they have the common arterial blood supply (the labyrinthine artery) and they have similar receptor cells [7]. Otolith

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organs (saccule and utricle) are part of the end organ of the vestibular system, which is sensitive to gravitational acceleration, and its dysfunction can be detected via vestibular-evoked myogenic potential (VEMP) responses [5]. VEMP test is used for detection of disorders of otolith organs and their pathway integrity [8−10]. VEMP test is an electrophysiological examination. There are two types of VEMP tests, the cervical VEMP (cVEMP) test and the ocular VEMP (oVEMP) test [11]. The cVEMP test can examine saccular function and the functioning of the inferior vestibular nerve input pathway, which has strong projections to the sternocleidomastoid muscle (SCM) [12]. The superior vestibular nerve input routes, which have potent projections to the oblique muscle of the lower eyelid, are examined by the oVEMP test together with utricular function [13]. The oVEMP is a short-latency potential, composed of extraocular myogenic responses activated by sound stimulation and registered by surface electromyography via ipsilateral, otolithic, and contralateral extraocular muscle activation [14,15]. A specific ocular muscle is stimulated by utricular stimulation [16,17]. While excitatory inputs protrude to the superior oblique, superior rectus, and medial rectus eye muscles ipsilaterally and the inferior oblique and inferior rectus eye muscles on the contralateral side [18]. The inferior oblique muscle is the most superficial of the six extraocular muscles responsible for eye movement. Therefore, measurement of oVEMPs can be performed easily by using surface electrodes on the skin below the eyes, contralaterally to the stimulated side [19].

## 2. Patients and methods

In our study, we recruited 40 participants that provided their consent for participation in all subjects of our study. The study was conducted in the Department of Audiovestibular at Hearing and Speech Institute, the age of the study groups ranged from 20 to 60 years. The control group (group A) consisted of 20 patients with bilateral normal peripheral hearing. The study group consisted of 20 patients with SSD (group B), both groups were free from any vestibular symptom. Testing was conducted in a sound-treated room model no RE. 24, acoustic immittance meter model Interacoustics AZ26 with a probe tone 220 Hz, pure-tone audiometer Interacoustics model AC40 with headphone TDH39 and bone vibrator B71. Each participant underwent a thorough medical history interview, a thorough audiological history, a basic audiological evaluation, including pure-tone audiometry for both bone conduction (for frequencies 500−4000 Hz) and air conduction (for frequencies 250−8000 Hz), speech audiometry, and immittancemetry. Vestibular evaluation was conducted with the caloric test and the evoked potential system GSI. As regards the oVEMPs, the patient on whom the test was being performed was instructed to look upward, staring at a fixed point, the fixed point is more than 2 m from the patient's eyes. Electrodes were placed such that the positive electrode was placed on the lower eyelid of each eye, with reference electrodes situated 1−2 cm below these and the ground electrode was placed on the forehead. Short-duration tone purist (95-dB nHL stimulus intensity) at a frequency of 500 Hz was presented through a headphone on the ear being tested, and the electromyography activity was recorded from the contralateral inferior oblique extraocular muscle using surface electrodes. The test was repeated twice on both sides to look for better superimposition of the waveforms. The latencies of N1 (N10) and P1 (P15) were measured. The amplitude of the waveform obtained was also calculated by the difference between the N1 and P1 (N10−P15). oVEMP tracing obtained consists of a biphasic waveform. The first peak has a negative deflection (N10) latency, followed by a positive peak (P15) latency, which are called N10 and P15, respectively. Because responses are recorded by surface electromyography, control of muscle contraction is imperative for reproducible and reliable results.

The cVEMP was performed using evoked potential system GSI Eclipse, and was recorded from the SCM. The active electrode was placed on the upper third of each SCM with a reference on the lateral end of the upper sternum, while the common electrode was placed on the forehead. During the test, patients were instructed to turn their heads toward the contralateral side of the tested ear to activate SCM. Stimuli presented mono-aurally, 500-Hz tone burst, were presented at a rate of five pulses per second and an intensity of 95 dBnHL. The mean peak latency (ms) of the P1 (P13) and N1 (N23) wave of the VEMP was measured. The peak-to-peak amplitude (μV) was measured for P13−N23 potentials.

As regards the caloric test, the patient was placed on a reclining chair with head elevated at an angle of 30° to the horizontal. Headband camera was placed over the eyes of the patient and the results recorded on Micro Medical Visual Eyes software (Interacoustics, Audiometer Allé 1, Middelfart, Denmark). Warm water at a temperature (~43.5 °C) into the external auditory canal for 40 s, followed by a recovery period, then cool (~30.5 °C) water for 40 s, and then canal paresis was calculated (abnormal: unilateral weakness>22 %).

### 2.1. Statistical analysis

Our data were coded, processed, and analyzed using Microsoft Excel software (Microsoft, Redmond, Washington, U.S.). This included data from historical data collection, basic clinical examinations, and outcome measurements. Data were then imported into Statistical Package for the Social Sciences (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) software for analysis. According to the type of data, qualitative represents as number and percentage, quantitative continuous group represents by mean ± SD, the following tests were used to test differences for significance difference and association of qualitative variables by $\chi^2$ test. Differences between quantitative independent groups by *t* test or Mann–Whitney, were paired by paired *t*, correlation by Pearson's correlation, or Spearman's agreement by Kappa. *P* value was set at less than 0.05 for significant results and less than 0.001 for high significant results.

## 3. Results

Our current study consisted of two groups, the control group (20 patients) group A, and study group (20 patients) group B. The participants enrolled in this study: their age range of 20–60 years, the mean age for the control group was 36.05 ± 9.17 years with an age range from 21 to 55 years, and mean age for the study group was 30 ± 9.02 years with an age range of 23–58. There was a non-statistically significant difference between the groups with regard to age. According to PTA and selection criteria, all patients in the study group (group B) had unilateral severe-to-profound hearing loss (SSD), in other words, the mean average for the frequencies 0.5, 1, 2, and 4 kHz should be more than or equal to 90-dBHL in one ear, whereas the good ear (contralateral side) hearing threshold average must be less than or equal to 30-dBHL. In controls (group A), hearing threshold average was within normal. All participants in the study groups had type-A tympanograms and speech discrimination scores matched with pure-tone average. As for the distribution of the unilateral SSD, 10 (50 %) patients had SSD in the right ear and 10 (50 %) patients in the left ear. The duration of SSD in the study group was 7.30 ± 3.19 years at right ears and 9.6 ± 7.93 years at left ears (i.e., duration of SSD in left ears >right ears).

Table 1 shows a highly statistically significant difference between the control group (group A) and study group B (patient with SSD) in the oVEMP test.

*Table 1. Comparison between control and study groups in ocular vestibular-evoked myogenic potential using t test (using mean, SD, and P values).*

| oVEMP | Group A | | Group B | | *t* test | *P* value |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | |
| N10 right | 10.13 | 0.25 | 6.13 | 1.16 | 3.36 | 0.002[a] |
| P15 right | 14.89 | 0.257 | 8.98 | 1.69 | 3.44 | 0.001[a] |
| AMP right | 16.82 | 1.78 | 10.89 | 2.38 | 1.98 | 0.054** |
| N10 left | 10.48 | 0.30 | 5.61 | 1.18 | 3.96 | 0.000[a] |
| P10 left | 15.05 | 0.24 | 8.11 | −1.69 | 4.05 | 0.000[a] |
| AMP left | 15.34 | 1.38 | 7.69 | 1.83 | 3.32 | 0.002[a] |

oVEMP, ocular vestibular-evoked myogenic potential.
[a] Highly statistically significant difference ($P < 0.01$).

*Table 2. Comparison between control and study groups in cervical vestibular-evoked myogenic potential using t test (using mean, SD, and P values).*

| cVEMP | Group A | | Group B | | *t* test | *P* value |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | |
| P13 right | 14.11 | 0.88 | 11.50 | 1.61 | 1.41 | 0.164 |
| N23 right | 23.88 | 1.41 | 19.57 | 2.67 | 1.42 | 0.163 |
| AMP right | 85.71 | 13.93 | 54.61 | 12.22 | 1.67 | 0.102 |
| P13 left | 14.99 | 0.78038 | 11.51 | 1.70 | 1.85 | 0.071[a] |
| N23 left | 24.30 | 0.77515 | 18.46 | 2.56 | 2.18 | 0.036[a] |
| AMP left | 116.44 | 16.48106 | 76.09 | 17.33 | 1.68 | 0.100 |

cVEMP, cervical vestibular-evoked myogenic potential.
[a] Statistically significant difference ($P < 0.05$).

Table 2 shows no statistically significant difference between the control group (group A) and study group B (patient with SSD) in cVEMP test, except in latency of P13 and N23 at the left ear.

Table 3 shows a highly statistically significant difference between the control group (group A) and study group B (patient with SSD) in caloric test.

Table 4 shows high correlation between the duration of SSD in group B and oVEMP test, cVEMP test, and caloric test (Figs. 1–7).

Fig. 8 shows the receiver-operating characteristic (ROC) curve of oVEMP, cVEMP, and caloric test of SSD in group B. ROC curve of oVEMP, the area under the curve was 0.934 with a significant *P* value and cutoff value of less than or equal to 8.9 as well as the sensitivity 95 %, the specificity 85 % with 95 % confidence interval (CI) 0.808–0.988. ROC curve of cVEMP, the area under the curve was 0.934 with a significant *P* value and cutoff value of less than 50.9

*Table 3. Comparison between control and study groups in caloric test using t test (using mean, SD, and P values).*

| Caloric | Control group | | Study group | | *t* test | *P* value |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | |
| Weakness | 13.90 % | 2.84 | 40.8 % | 27.72 | 4.316 | 0.000[a] |

[a] Highly statistically significant difference ($P < 0.01$).

*Table 4. Spearman's correlation coefficient between vestibular-evoked myogenic potential test (ocular vestibular-evoked myogenic potential and cervical vestibular-evoked myogenic potential), caloric test, and duration of single-sided deafness of all ears (right ears and left ears) in group B.*

| VEMP | Duration | |
|---|---|---|
| | *r* | *P* value |
| N10 oVEMP | −0.458 | 0.042[a] |
| P15 oVEMP | −0.458 | 0.042[a] |
| AMP oVEMP | −0.468 | 0.038[a] |
| P13 cVEMP | −0.486 | 0.03[a] |
| N23 cVEMP | −0.528 | 0.017[a] |
| AMP cVEMP | −0.423 | 0.063[a] |
| Caloric | 0.428 | 0.059[a] |

cVEMP, cervical vestibular-evoked myogenic potential; oVEMP, ocular vestibular-evoked myogenic potential.
[a] Correlation is significant at the 0.05 level (two-tailed).

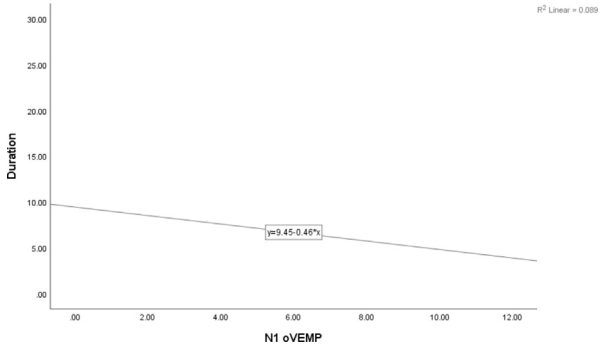


*Fig. 1. Spearman's correlation coefficient between duration of SSD in group B and latency of N1 (N10) of oVEMP. oVEMP, ocular vestibular-evoked myogenic potential; SSD, single-sided deafness.*

as well as the sensitivity 95 %, the specificity 80 % with 95 % CI 0.763−0.972. ROC curve of caloric, the area under the curve for 0.850 with significant *P* value and cutoff value more than 20, as well as the sensitivity 55 %, the specificity 95 % with 95 % CI 0.702−0.943 (Table 5).

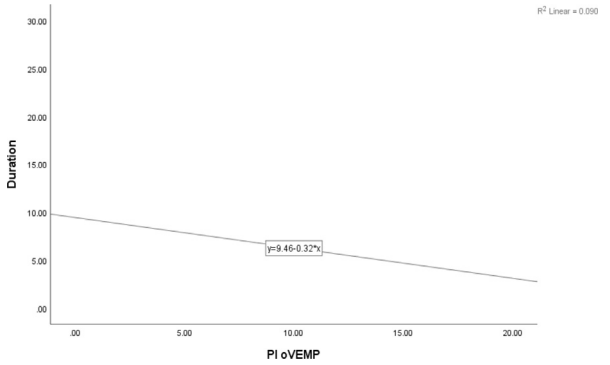


*Fig. 2. Spearman's correlation coefficient between duration of SSD in group B and latency of P1 (P15) of oVEMP. oVEMP, ocular vestibular-evoked myogenic potential; SSD, single-sided deafness.*

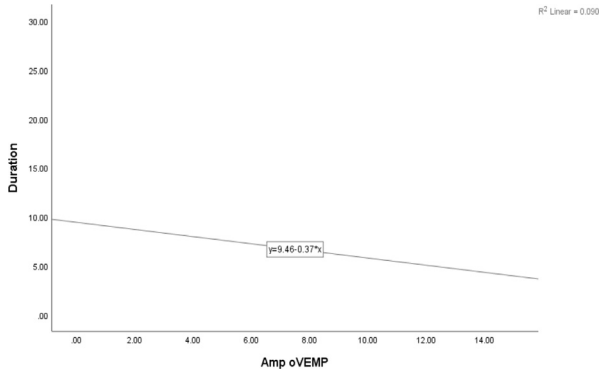


*Fig. 3. Spearman's correlation coefficient between duration of SSD in group B and amplitude of oVEMP. oVEMP, ocular vestibular-evoked myogenic potential; SSD, single-sided deafness.*

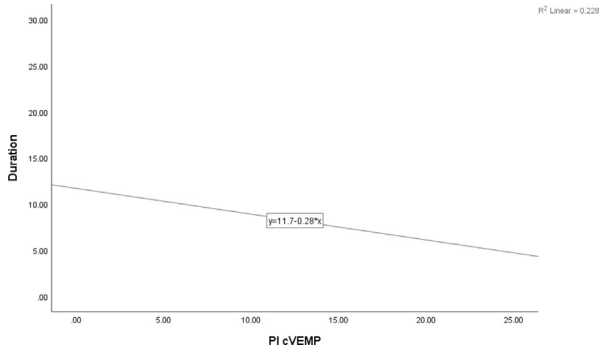


*Fig. 4. Spearman's correlation coefficient between duration of SSD in group B and latency of P1 (P13) of cVEMP. cVEMP, cervical vestibular-evoked myogenic potential; SSD, single-sided deafness.*

## 4. Discussion

SSD is defined as severe-to-profound sensorineural hearing loss in one ear and with normal or near-to-normal hearing in the other ear. The symptoms of SSD are hearing loss with a poor word recognition ability [1]. SSD is often associated with the vestibular system such as nausea, vertigo, and

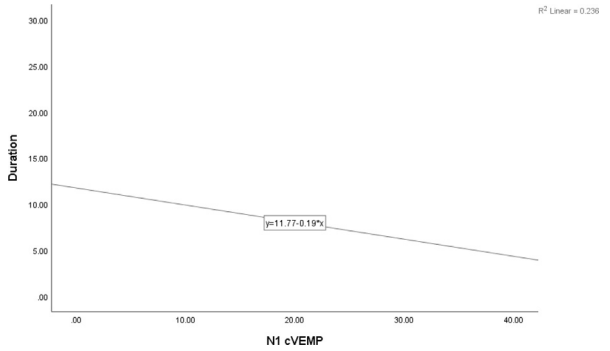


*Fig. 5. Spearman's correlation coefficient between duration of SSD in group B and latency of N1 (N23) of cVEMP. cVEMP, cervical vestibular-evoked myogenic potential; SSD, single-sided deafness.*

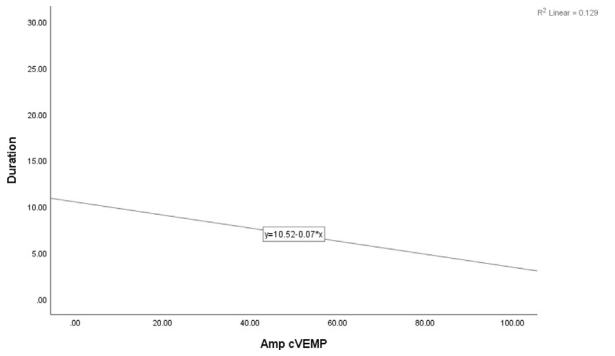


*Fig. 6. Spearman's correlation coefficient between duration of SSD in group B and amplitude of cVEMP. cVEMP, cervical vestibular-evoked myogenic potential; SSD, single-sided deafness.*

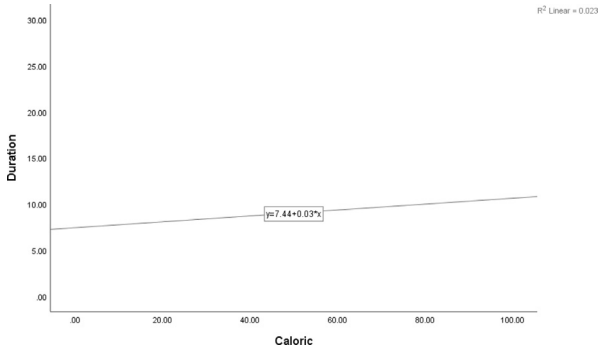


*Fig. 7. Spearman's correlation coefficient between duration of SSD in group B and caloric test. SSD, single-sided deafness.*

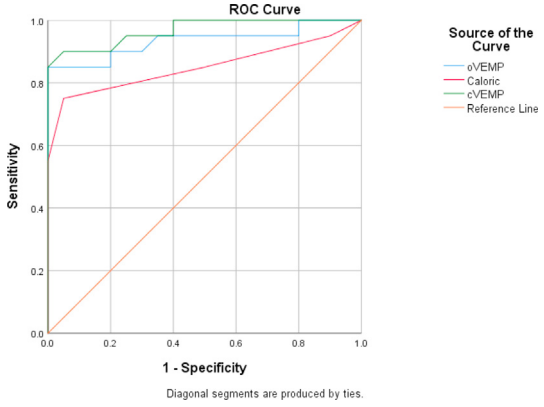


*Fig. 8. ROC curve of oVEMP, cVEMP, and caloric test of SSD in group B. cVEMP, cervical vestibular-evoked myogenic potential; oVEMP, ocular vestibular-evoked myogenic potential; ROC, receiver-operating characteristic; SSD, single-sided deafness.*

imbalance; moreover, the incidence of otolithic damage is very high [6]. Forty adult patients were included in our study, with mean age for the control group (group A) 36.05 ± 9.17 years with an age range of 21−55 years. The mean age for the patient with SSD (group B) was 30 ± 9.02 years with an age range 23−58 years. The patients enrolled in our study (group B) were found to all have unilateral SSD, 10 (50 %) had SSD in the right ear and 10 (50 %) in the left ear and duration of SSD in the study group was 7.30 ± 3.19 years at right ears and 9.6 ± 7.93 years at left ears (i.e., duration of SSD in left ears >right ears). We can detect oVEMP in 35 % and cVEMP in 55 % patients with SSD, while both can be detected 100 % in the healthy control group.

In this study, when comparing the results of oVEMP between the study and the control group, we found that there was a highly significant difference between them (Table 1). As regards VEMP test parameters, it includes latency of P1, N1, and inter-amplitude N1−P1. It can detect disorders of otolith organs and accuracy of their pathway's integrity [8−10]. In the oVEMP test in Table 1, we found low score of all parameters either in latency of N1 (N10) and P1 (P15) or interamplitude N1−P1 (N10−P15). Our findings in this research means that there was a great association between SSD and disorder of utricular function and the functioning of the superior vestibular nerve input pathways. These findings are in agreement with Sazgar et al. [7] who demonstrated that, from the anatomical view, the cochlea and the vestibular system commonly share in the same membranous labyrinth, moreover, functional similarities of hearing and vestibular systems. They are frequently affected by the same pathophysiological factors. Furthermore, Beck et al. [6] report that 70 % of children with sensorineural hearing loss have vestibular system disturbance and long-term changes in one of them can cause big damage in the other. On the contrary to our research, Xu et al. [4] and Chihara et al. [18] concluded that there was no difference between the control group and the group with affected ears with SSD in the latencies of the P1 and N1 of both cVEMP and oVEMP. Otherwise, Akkuzu et al. [20] reported prolonged latency of

*Table 5. Sensitivity and specificity of ocular vestibular-evoked myogenic potential, cervical vestibular-evoked myogenic potential test, and caloric test of single-sided deafness in group B.*

| | Area under curve | Cutoff value | Asymptotic significance *B* | Asymptotic 95 % confidence interval | | Specificity | Sensitivity |
|---|---|---|---|---|---|---|---|
| | | | | Lower bound | Upper bound | | |
| oVEMP test | 0.934 | ≤8.9 | 0.0001 | 0.808 | 0.988 | 85 % | 90 % |
| cVEMP test | 0.934 | ≤50.9 | 0.0001 | 0.763 | 0.972 | 80 % | 80 % |
| Caloric test | 0.850 | >20 | 0.0001 | 0.702 | 0.943 | 55 % | 95 % |

cVEMP, cervical vestibular-evoked myogenic potential; oVEMP, ocular vestibular-evoked myogenic potential.

VEMP test in SSD, this latency is not affected by otolith damage similar as cochlear damage, this prolongation was affected by a change in reflex pathways of sacculocollic and vestibulo-ocular [21].

As regards cVEMP, when comparing the results of the cVEMP test between the study and the control group in Table 2, the results showed that, at right ears, the mean latency of P1 (P13) in the study group was 11.50 ± 1.61 and the mean latency of N1 (N23) was 19.57 ± 2.67 and interamplitude P1–N1 (P13–N23) was 54.61 ± 12.22. These results showed a nonsignificant difference than the control group. On the other hand, at the left ear, the mean latency of P1 (P13) in the study group was 11.51 ± 1.70 and mean latency of N1 (N23) was 18.46 ± 2.56, the results showed a significant difference than the control group as regards the latency of cVEMP in left ears. Otherwise, interamplitude P1–N1 (P13–N23) was 76.09 ± 17.33. The results showed a nonsignificant difference than the control group in left ears.

According to our speculation, these findings related to the fact that duration of SSD in left ears was longer than that in right ears. These findings agree with Inoue et al. [22] who reported that children with severe-to-profound sensorineural hearing loss may cause long-term changes in the cochlea and with prolonged time these can cause big damage in the vestibular system. These deficiencies could affect both the inferior and superior vestibular nerve systems. Moreover, in our study, oVEMP can be detected in 35 % and cVEMP can be detected in 55 % of patients with SSD, while 100 % of both can be detected in the healthy control group. Our speculation may be related to the pathogenesis of the inner ear diseases causing otolith organ receptor cells unable to react to the sound stimulation. In addition, our results showed that oVEMPs were more absent than cVEMPs. These findings suggested that utricular could be closely linked to the cochlea than saccular in SSD individuals.

These findings agree with Xu et al. [4] who reported that in patients with substantial sensorineural hearing loss, oVEMP responses were recorded in 58.1 % of ears and cVEMP responses in 61.9 % of ears. In addition, these patients may not exhibit signs of vestibular and otolithic organ dysfunction.

On the other hand, this is contradictory to the results from a study by Khan et al. [23] who reported that 76.47 % of patients with SSD had normal VEMP and 23.53 % had absent and abnormal VEMP. Moreover, Trivelli et al. [24] and Zhou and Cox [25] demonstrated that there was no difference between normal hearing threshold and patients with SSD as regards the latencies of VEMP test. They hypothesized that there are variations in VEMP amplitudes and these depend on several factors such as intensity of sound stimuli and on the muscle tension [24,25].

When comparing the results of caloric test between the study and the control group, we found that there was a significant difference between them (Table 3). These findings confirmed that there is a great association between balance and vestibular disorders with sensorineural hearing loss. These agree with Cushing et al. [26] who demonstrated that in a cross-sectional study, children with profound sensorineural hearing loss were tested with caloric, rotational stimuli responses of the horizontal canal, and in VEMP, half of the children presented vestibular end-organ dysfunction. Moreover, Birdane [27] reported that vestibular impairment can occur unilaterally in children with SSD and this causes balance impairment, and that it is less severe than bilateral profound sensorineural hearing loss.

In our current study, as regards the effect of duration of SSD in group B, there were highly statistically significant differences noticed between patients with SSD and parameters of VEMP (oVEMP and cVEMP) test and caloric test (Table 4). Our findings agree with Santos et al. [28], who reported that the relation between hearing loss and vestibular disorders is very large and these relations depend on the age onset of hearing loss.

We can show that the caloric test was the most specific test for identifying vestibular signs in patients with SSD who are asymptomatic and have never complained of vestibular dysfunction when we used the ROC curve to measure the sensitivity and specificity of each test (Fig. 5). The most sensitive test was oVEMP.

### *4.1. Conclusion*

Vestibular end organs may be damaged in SSD individuals who are asymptomatic and have never complained of vestibular dysfunction, which would account for the absence of cVEMP and oVEMP in these patients. In addition, oVEMPs were able to identify vestibular signs in these patients. Moreover, oVEMP test is the most sensitive and the caloric test is most specific for identifying vestibular signs in these patients. Furthermore, otolithic organ pathways may be affected in patients with SSD. Measurement of oVEMPs can be performed easily by using surface electrodes on the skin below the eyes, contralaterally to the stimulated side [19].

### *4.2. Recommendations*

More research is required to determine the relationship between the duration of onset hearing loss

and vestibular symptoms and signs using the oVEMP test and the cVEMP in both early and late stages of SSD. In addition, it is important to pinpoint the pathophysiology of SSD that influences how early-onset and late-time-delayed hearing loss are affected by vestibular signs.

## Ethical approval

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee.

### Conflicts of interest

None declared.

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