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Influence of the Electrode Montage to Detect Ocular Vestibular Evoked Myogenic Potentials

*†Quentin Mat, ‡Naïma Deggouj, *Jean-Pierre Duterme, *Sophie Tainmont, †§Christophe Lelubre, and †||Mario Manto

*Department of Otorhinolaryngology, C.H.U. Charleroi, Charleroi 6042, Belgium; †Faculty of Medicine and Pharmacy, University of Mons (UMons), Mons 7000, Belgium; ‡Department of Otorhinolaryngology and Head and Neck Surgery, Cliniques Universitaires Saint-Luc, UCLouvain (UCL), Brussels 1200, Belgium; §Department of Internal Medicine, C.H.U. Charleroi, Charleroi 6042, Belgium; and ||Department of Neurology, Médiathèque Jean Jacquy, C.H.U. Charleroi, Charleroi 6042, Belgium

Objective: To compare ocular vestibular evoked myogenic potentials (oVEMPs) obtained with three different electrode montages (infra-orbital vs belly-tendon vs chin) in a group of healthy subjects. To assess the electrical activity recorded at the level of the reference electrode in the belly-tendon and chin montages.
Study Design: Prospective study.
Setting: Tertiary referral center.
Patients: Twenty-five healthy adult volunteers.
Intervention(s): Each ear was tested separately via air-conducted sound (500 Hz Narrow Band CE-Chirps at 100 dB nHL) for recording contralateral myogenic responses. Recording conditions were randomized.
Main Outcome Measure(s): n1-p1 amplitudes values, interaural amplitude asymmetry ratios (ARs) and response rates.
Results: The belly-tendon electrode montage (BTEM) produced larger amplitudes than the chin ($p = 0.008$) and the IOEM (infra-orbital electrode montage; $p < 0.001$). The chin montage displayed larger amplitudes than the IOEM ($p < 0.001$). The interaural amplitude asymmetry ratios (ARs) were not affected by the different electrode montages ($p = 0.549$). In 100% of cases, oVEMPs were detected bilaterally with the BTEM which is higher than with the chin and the IOEM ($p < 0.001$; $p = 0.020$, respectively). We did not record any VEMP when placing the active electrode on the contralateral internal canthus or the chin and the reference electrode on the dorsum of the hand.
Conclusions: The BTEM increased the amplitudes recorded and response rate in healthy subjects. No positive or negative reference contamination was observed with the belly-tendon or chin montages.
Key Words: Belly-tendon—Electrode montage—Air conduction—electrode montage—Narrow band CE-chirp—Ocular vestibular evoked myogenic potential.
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INTRODUCTION

Vestibular evoked myogenic potentials (VEMPs) are used to assess otolithic organs and otolith-mediated pathways (1,2). Cervical VEMPs (cVEMPs) are myogenic reflexes of saccular origin (3,4). They are best recorded by a belly-tendon electrode montage (BTEM) on the ipsilateral sternocleidomastoid muscle (5). Ocular vestibular-evoked myogenic potentials (oVEMPs) assess the utricle and the superior vestibular nerve (6). The activated response originates from the contralateral inferior oblique muscle when the individual looks upward (7). The infraorbital electrode montage (IOEM) has been the most described and remains the "gold standard" for recording oVEMPs (2,8). This setup has major limitations such as low recorded amplitudes and a high rate of absent responses in healthy subjects (9,10). Other promising electrode montages as the chin and the belly-tendon (BT) have been reported and could improve the registration of oVEMPs (11,12). The aims of this study were to compare the n1-p1 amplitudes values, interaural amplitude asymmetry ratios (ARs) and response rates obtained in oVEMPs with these three electrode montages (IOEM vs BTEM vs chin) in a group of healthy subjects. A secondary objective was to evaluate the electrical activity recorded at the level of the reference electrode in the BT and chin montages.

Address correspondence and reprint requests to Quentin MAT, Chaussée de Bruxelles, 140, 6042 Charleroi, Belgium; E-mail: quentin.mat@outlook.com
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Author contributions: Q.M. designed and conceptualized the study, conducted the experiment, analyzed, and collected the data, and wrote and revised the article. N.D, J.-P.D., S.T., and M.M. designed the study and revised the article. C.L. designed the study, interpreted the data, and revised the article. All the authors approved the final version.

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METHODS

Subjects

A group of 25 healthy volunteers with no otologic or neurologic disorder were included in this prospective study (13 men, 12 women; median age = 22 years, Q1–Q3 = 21–28 years, range = 18–44 years). Exclusion criteria were identified by means of anamnesis and a series of pre-tests whose calibration was checked before the start of the study (Table 1): micro-otoscopy (Zeiss OPMI Pico, Germany), tympanometry at 226 Hz (GSI Tympstar Grason-stadler, Eden Prairie, MN, USA), air and bone-conducted pure-tone liminar audiometry with a TDH 39 headphone and B71 bone vibrator (Equinox, Interacoustics, Middelfart, Denmark), speech audiometry with French Fournier's disyllabic word lists (Equinox, Interacoustics, Middelfart, Denmark). The last two examinations were performed in a sound-treated audiometric test booth (Boët Stopson, Villeneuve d'Ascq, France).

Recording Procedure of oVEMPs

Participants were seated in a height-adjustable chair in a soundproof and faradized booth (BERA, Boët StopSon, Villeneuve d'Ascq, France). While releasing tension in the face, they were instructed to maintain focus on a bright red target on the opposite wall, 2 m away in order to prevent accommodation during the recording procedure. The visual target formed an upward angle of 30 degrees with a horizontal plane corresponding to the rest position of the eyes. The option to adjust the height of the chair makes it possible to maintain the angle constant despite the different sizes of the individuals. Skin was prepared (Nuprep Skin Prep Gel, Weaver and Compagny, Colorado, USA and Ether®) and surface electrodes were used (133 Foam Electrodes, Covidien™, MA, USA). Three electrode montages have been consecutively assessed (Fig. 1). In the IOEM, the active electrode was placed on the orbital margin under the center of the eye and the reference electrode 2 cm beneath the active electrode (8). In the chin montage, the active electrode was located at the same place as for the IOEM and the reference electrode was on the chin (11). For the BTEM, the active electrode was located 1 cm under the free edge of the inferior eyelid contralateral to the stimulation, slightly shifted outward when compared with the middle of the eye. In this way, the electrode was placed close to the inferior oblique muscle on the skin. The reference electrode was placed in the internal canthus (12). For each modality, the ground electrode was placed on the forehead. The oVEMPs responses were measured contralateral to the stimulation ear. The electrode impedance was kept below 5 kΩ and the interelectrode impedance was below 3 kΩ. Insert earphones (INSERT 3 M E-A-RTONE™ 3A, Minneapolis, USA) were put in each ear. Men were asked to shave their beards before taking part in the study. The recording of the myogenic response and the sound delivery were carried out using the Eclipse EP25 module (Interacoustics, Assens, Denmark) according to a proper calibration based on the International Organization for Standardization ISO 389-6. Each ear was tested separately via air-conducted sound for recording contralateral myogenic responses. For each ear, sound stimuli generated were Narrow Band CE-Chirps (NB CE-Chirps) at the intensity level of 100 dB nHL (normalized hearing level; corresponding to 125,5 dB peak SPL) at the frequency of 500 Hz. NB CE-chirps were chosen because they showed larger amplitudes values in oVEMPs and cVEMPS than Tone Bursts at the frequency of 500 Hz on healthy subjects (14–18). The duration of the NB CE-Chirps was 9 ms for 500 Hz (range 360–720 Hz). They were repeated 100 times for one acquisition. For each subject, equivalent sound energy exposure (LAeq) was calculated before the start of the study and was equivalent to 130 dB A for 1 second (19,20). Based on the optimal parameters reported in the literature (1,2,21), a repetition rate of 5.1/s with a rarefaction polarity and a band-pass filter of 1 to 1,000 Hz were selected. Electrical activity was recorded from 20 ms before to 80 ms following stimulus onset. For each participant the initial tested ear as well as the order of the recording montages were also randomized to exclude a fatigue effect. Each recording procedure was repeated twice, and the measured values were averaged. A response was considered to be present only if a biphasic wave was identified at the expected latencies with a larger amplitude than the recorded pre-stimulus noise. The participant was granted 1-minute rest between each recording.

The variables of interest were the peak-to-peak amplitudes n1-p1 (μV) and the n1 and p1 latencies (ms) (Fig. 2). Interaural amplitude asymmetry ratios (ARs) were computed using the following formula: AR (%) = 100 × [biggest amplitude (μV) − smallest amplitude (μV)] / [biggest amplitude (μV) + smallest amplitude (μV)] (21).

Finally, to determine whether the chin and the internal canthus were electrically indifferent recording electrode sites, a subgroup of 10 subjects (6 men, 4 women; median = 30.5 years, Q1–Q3 = 21.5–36.5 years, range = 19–44 years) from the first

TABLE 1. *Exclusion criteria*

Exclusion Criteria	Definition of the Criteria
Conductive or mixed hearing loss	Rinne strictly higher than 10 dB on one of the tested frequencies
Suspicion of retrocochlear pathology	Discrepancy between speech audiometry and pure-tone audiometry
Asymmetric neurosensory hearing loss	Asymmetry higher than 15 dB in comparison with the average frequencies 500–1,000–2,000 and 4,000 Hz (13)
Previous otologic problems or balance problems	
Previous oculomotor problems	
Neurological or muscular pathology impairing myogenic responses	
Type 1 or 2 diabetes mellitus	
Taking ototoxic or myorelaxant medication	
Age <18 years	

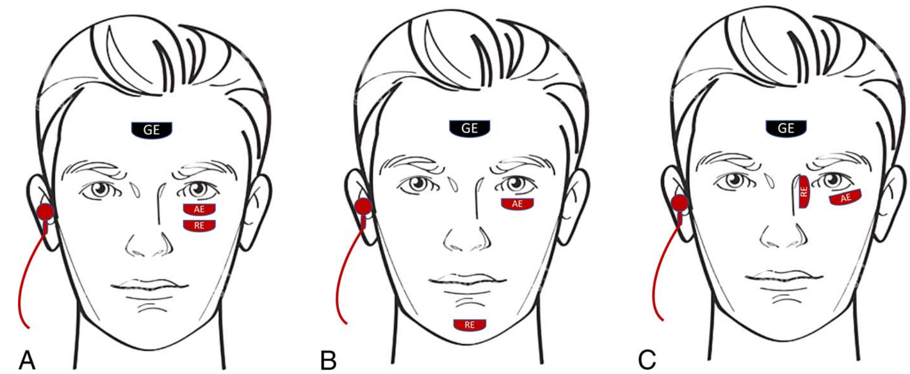

FIG. 1. Description of the different electrode montages used for oVEMPs. Each myogenic response was recorded contralaterally to the sound stimulation. NB CE-Chirps 500 Hz were delivered with inserts. (A) In the IOEM, the active electrode (AE) was placed on the orbital margin under the center of the eye and the reference electrode (RE) 2 cm beneath the active electrode. (B) In the chin montage, the active electrode (AE) was located at the same place as for the IOEM and the reference electrode (RE) was on the chin. (C) With the BTEM, the active electrode (AE) was located 1 cm under the free edge of the inferior eyelid slightly shifted outward when compared with the middle of the eye. The reference electrode (RE) was placed in the internal canthus. The ground electrode (GE) was placed on the forehead for the three electrode montages. NB CE-Chirp indicates Narrow band CE-Chirp; oVEMP, ocular vestibular evoked myogenic potential; IOEM, infra-orbital electrode montage; BTEM, belly-tendon electrode montage.

part of the study was recruited. The active electrode was successively placed on the chin and the internal canthus, and the reference electrode was located on the dorsum of the hand contralateral to stimulation ear (11,23). The ground electrode was still on the forehead. It was asked to release the hand during the recording. The running order was also randomized. Stimulus and recording parameters were identical to those used to record oVEMPs in the first part of the study. To minimize noise exposure, this part of the research was carried out at least 48 hours after the first investigation.

Statistical Analysis

We analyzed the peak-to-peak amplitudes n1-p1, the n1 and p1 latencies and the interaural asymmetry ratios. Continuous variables were described using means and standard deviations or medians and interquartile ranges according to the normality of parent distributions. Normality was assessed using QQ plots and Shapiro-Wilk's tests. Continuous variables were compared using non parametric procedures for paired data (Friedman's tests), with Dunn-Bonferroni procedures for post hoc multiple comparisons. The rate of responses for the different electrode montages was compared by a Cochran's Q test and Bonferroni correction for multiple comparisons. All tests were two-sided with an alpha error level at 0.05. A p-value <0.05 was considered significant. Statistical analyses were conducted using the software IBM® SPSS® Statistics version 23.0 (IBM, Ehningen, Germany).

Ethics Approval Statement

Approval for any experiments was obtained from the institutional ethics committee (CCB: B4062020000247) and written informed consent was obtained from all participants for this study.

RESULTS

For the same electrode montage, left and right ears did not demonstrate any statistical differences for n1-p1 amplitudes and n1 and p1 latencies ($p > 0.05$, Friedman's test followed by Dunn-Bonferroni). Consequently, the data obtained by

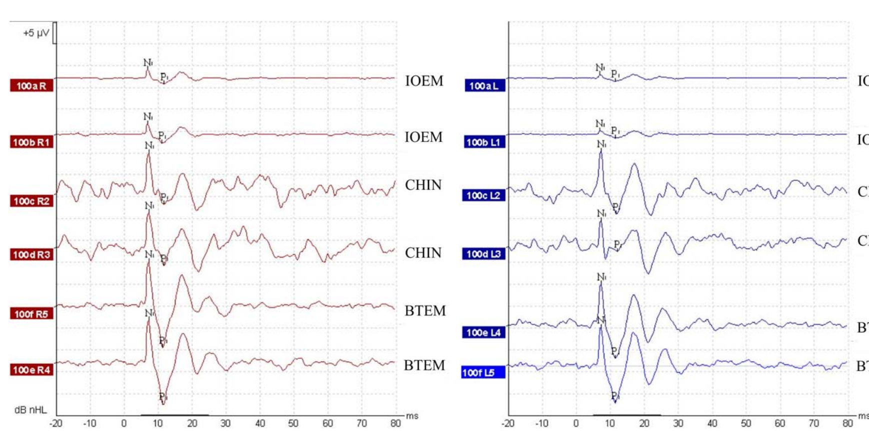

FIG. 2. Example of oVEMP waveforms recorded in a healthy volunteer with NB CE-chirp 500 Hz. Waveforms recorded for the right ear (red) and the left ear (blue) according to the electrode montage (IOEM, Chin montage and BTEM). NB CE-Chirp indicates Narrow band CE-Chirp; oVEMP, ocular vestibular evoked myogenic potential; IOEM, infra-orbital electrode montage; BTEM, belly-tendon electrode montage.

TABLE 2. *Descriptive data of n1-p1 amplitude, n1 and p1 latencies and AR according to the electrode montage used with NB CE-chirp 500 Hz*

Stimulus	NB CE-Chirp 500 Hz		
Electrode Montage	IOEM	Chin	BTEM
n1-p1 amplitude (μV)			
Median (Q1–Q3)	3.81 (1.77–7.48)	12.67 (6.55–22.72)	13.49 (6.62–23.75)
n1 latency (ms)			
Median (Q1–Q3)	7.00 (6.67–8.17)	7.33 (7.00–8.08)	7.25 (7.00–8.00)
p1 latency (ms)			
Median (Q1–Q3)	12.00 (11.33–13.17)	12.75 (11.71–13.62)	12.00 (11.33–12.83)
AR			
Median (Q1–Q3)	32.71 (9.08–52.10)	20.64 (5.71–32.65)	18.21 (12.4–27.82)

AR, interaural asymmetry ratio; BTEM, belly-tendon electrode montage; IOEM, infraorbital electrode montage; NB CE-Chirp, narrow band CE-Chirp; Q, quartile.

both ears were pooled for each montage. The descriptive data of the studied parameters are reported in Table 2.

N1-p1 amplitudes showed significant differences according to the electrode assembly ($p < 0.001$, effect size = 0.833, Friedman's test). The BTEM produced larger amplitudes (median = 13.49 μV) than the chin (median = 12.67 μV) ($p = 0.008$, Dunn-Bonferroni) and the IOEM (median = 3.81 μV) ($p < 0.001$, Dunn-Bonferroni). The chin montage displayed larger amplitudes than the IOEM ($p < 0.001$, Dunn-Bonferroni) (Fig. 3(A)).

The electrode montage significantly affected n1 latencies ($p < 0.001$, effect size = 0.219, Friedman's test). They were longer with the chin montage compared with the IOEM ($p = 0.002$, Dunn-Bonferroni). There were no differences between the BTEM and the IOEM ($p = 0.335$, Dunn-Bonferroni) and between the BTEM and the chin montage ($p = 0.231$, Dunn-Bonferroni) for n1 latencies (Fig. 3(B)).

P1 latencies were also influenced by the montage ($p = 0.001$, effect size = 0.209, Friedman's test) with longer latencies for the chin montage in comparison with the IOEM ($p = 0.004$, Dunn-Bonferroni) and the BTEM ($p = 0.004$, Dunn-Bonferroni). There were no significant p1 latencies differences between the BTEM and the IOEM ($p = 1.000$, Dunn-Bonferroni) (Fig. 3(C)).

ARs did not change significantly according to the chosen electrode montage ($p = 0.549$, Friedman's test).

Depending on the electrode assembly used, different response rates were observed ($p < 0.001$, Cochran's Q test) (Table 3). In 100% of cases, oVEMPs were detected bilaterally with the BTEM which is significantly higher than with the chin and the IOEM ($p < 0.001$; $p = 0.020$, respectively; Dunn-Bonferroni).

Finally, we did not record any VEMP after air-conducted stimulation when placing the active electrode on the contralateral internal canthus or the chin and the reference on the dorsum of the hand.

DISCUSSION

oVEMPs are short latency myogenic reflexes that originate from the utricle (24). Because of their low amplitude and the many surrounding periocular and facial muscles, it is still difficult to record them and a high rate of absent responses is observed in healthy subjects (2,9,10,25). Improving the recording of n1-p1 waves is essential to increase the observer's confidence in detecting peaks and allow better assessment of utricular function. In this study, the BTEM showed the largest n1-p1 amplitudes. We also observed larger amplitudes with the chin montage than the IOEM. Several factors could explain these results. First, reference contamination has been reported with the IOEM (11,12,26). This setup is described as highly selective for recording inferior oblique muscle contraction and reducing ambient noise (2,8). However, because of the proximity of the electrodes in this bipolar assembly, a large part of the myogenic response is registered by the reference and the active electrodes together, which could cover up a large part of the signal and explain the lower responses recorded (23,27). In the BTEM, it was hypothesized that the larger amplitudes could come from a positive reference contamination (23). Indeed, the internal canthus could be a phase shifted electrical area where the signal would be in phase opposition with that produced by the contraction of the inferior oblique muscle, improving the amplitude of the recorded curves. This phase opposition would originate from an activation of another oculomotor muscle (the internal rectus muscle for instance) or from a stationary wave's phenomenon at the level of the tendon of the inferior oblique muscle (12,23,28,29). The BTEM could also be free of reference contamination and the internal canthus could be an electrically neutral area (11,12,23,26). Finally, moving the active electrode slightly outwards as with the BTEM would allow larger amplitudes to be recorded. In this way, the active electrode would then be better placed in front of the inferior oblique muscle (12,26). However, involvement of the external rectus muscle is not excluded (28).

In the chin montage, the reference electrode is located away from the oculomotor muscles and therefore from the vestibulo-ocular reflex (VOR) (11). This assembly would then allow not to have negative reference contamination but would increase the risk of contamination of the signal by the surrounding noise due to the significant distance that separates the active and reference electrodes as observed in our study (12,30). This would explain the better amplitudes obtained with the chin montage than with the IOEM but lower in comparison with the BTEM. We actually observed more artefactual curves with the chin assembly. Lastly, the chin montage requires shaving the beard which can be disruptive for many men. To better understand the electrical

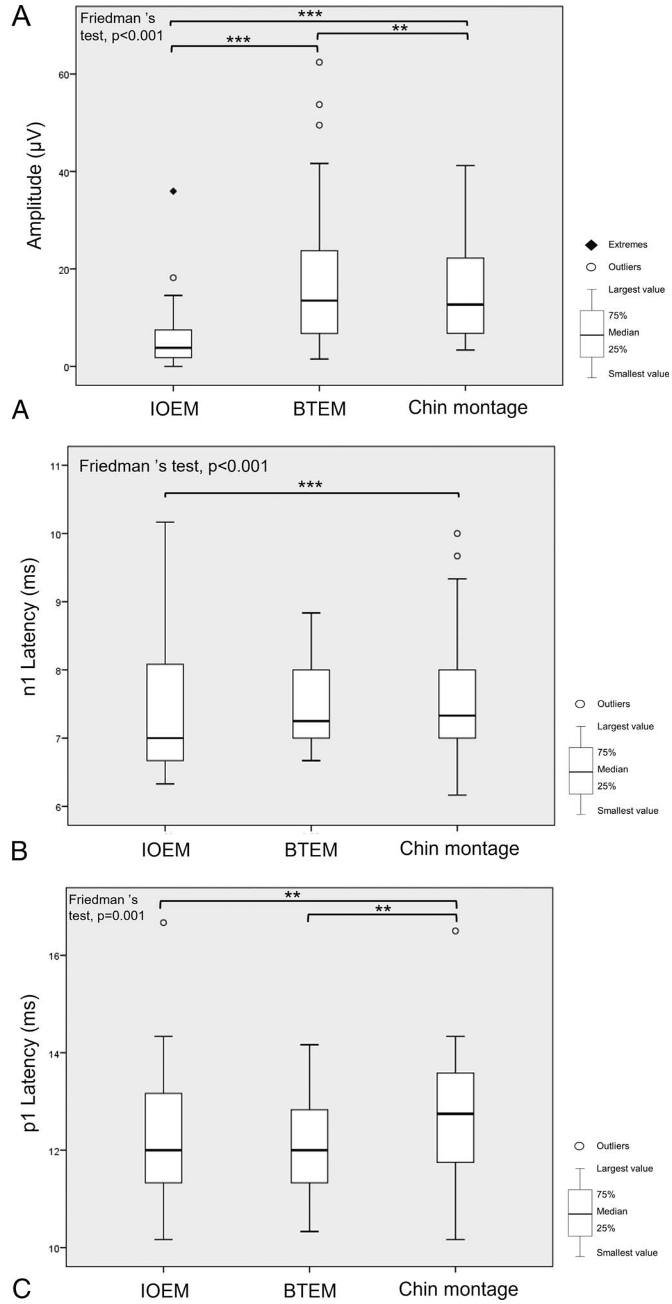

FIG. 3. Boxplots of peak to peak amplitudes, n1 latency and p1 latency.Peak to peak amplitudes (A) (μV), n1 latency (B) and p1 latency (C) (ms) obtained according to the electrode montage used for oVEMPs. All pairwise comparisons are topped with * when they are significantly different (Dunn-Bonferroni procedure). Data are presented as boxplots indicating the first and the third quartiles centered on medians (thick lines) with whiskers for the minimum and maximum nonoutlier values, o are outliers, and ♦ show the extreme values. oVEMP, ocular vestibular evoked myogenic potential; IOEM, infra-orbital electrode montage; BTEM, belly-tendon electrode montage.

signal recorded at the reference sites of the chin and BT montages, we reconvened ten participants from this study another day. The active electrode was this time positioned on the internal canthus contralateral to the sound stimulation or on the chin. The reference electrode was then placed on the dorsum of the hand contralateral to stimulation ear which has the advantage of not having VOR (11,23). The ground electrode was still on the forehead and each subject then performed the two analyzes randomly. We did not record any particular myogenic response in these two conditions suggesting that there would be no reference contamination with the chin and BTEM. There was also increased background noise when the active electrode was placed on the participants' chin. This would originate from the significant musculature of this region.

Regarding response rates, they were significantly higher with the BTEM than with the chin and the IOEM. This result agrees with the magnitude of the amplitudes recorded

TABLE 3. *Response rates obtained according to the electrode montage with NB CE-chirp 500 Hz*

NB CE-Chirp 500 Hz	
Electrode Montage	Response Rate (%)
IOEM (n = 50 ears)	86
BTEM (n = 50 ears)	100
Chin (n = 50 ears)	80

BTEM, belly-tendon electrode montage; IOEM, infra-orbital electrode montage; NB CE-Chirp, narrow band CE-Chirp.

with the BTEM and the more significant parasitic noise observed with the chin assembly.

The n1 and p1 latencies were also influenced by the studied montage. Indeed, we observed longer n1 and p1 latencies with the chin compared with the IOEM. P1 latencies were also longer with the chin than the BTEM. This could be due to the change in position of the reference electrode. Several studies have shown that moving the reference electrode can alter the recorded latencies of compound muscle actions potentials (31,32). This has also been shown in oVEMPs that different electrode montage could modify n1 and p1 latencies (27–29). These differences in latencies for the different electrode montages should be considered in case of suspicion of central nervous system disorders as multiple sclerosis, spinocerebellar degeneration, brainstem infarction and Parkinson's disease in which the latencies could be lengthened (33). In addition, the observed n1 and p1 latencies with the three electrode montages were shorter than those usually reported with 500 Hz Tone Bursts because the presentation time of the sound stimulus is earlier with 500 Hz NB CE-Chirps (17,34). It has also been suggested that primary vestibular neurons may have double or triple firing to one Tone burst and the latencies of VEMPs responses might be delayed to this second or third spikes, unlike NB CE-Chirps (35).

Finally, the ARs were not significantly affected by the different electrode montages. Similar findings were reported in the literature (11,23). However, some authors have reported lower ARs with BTEM compared with IOEM (27,28). In our study, the median of the asymmetry ratios was lower with the BTEM than with the IOEM. It is possible that the absence of significance is linked to a lack of participants.

Additional studies with a larger cohort of participants including older subjects and patients with peripheral vestibular disorders will be necessary in order to confirm these observations.

CONCLUSION

oVEMPs are short latency myogenic reflexes whose recording is complicated by their low amplitudes. The BTEM increased the amplitudes recorded and response rate compared with the chin and the IOEM in healthy subjects. No positive or negative reference contamination was observed with the belly-tendon or chin montages.

Additional studies on patients with peripheral vestibular damage are needed to recommend BTEM for clinical application.

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REFERENCES

1. Colebatch JG, Rosengren SM, Welgampola MS. Vestibular-evoked myogenic potentials. *Handb Clin Neurol* 2016;137:133–55.
2. Rosengren SM, Colebatch JG, Young AS, Govender S, Welgampola MS. Vestibular evoked myogenic potentials in practice: methods, pitfalls and clinical applications. *Clin Neurophysiol Pract* 2019;4:47–68.
3. Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. *J Neurol Neurosurg Psychiatry* 1994;57:190–7.
4. Papathanasiou ES, Murofushi T, Akin FW, Colebatch JG. International guidelines for the clinical application of cervical vestibular evoked myogenic potentials: an expert consensus report. *Clin Neurophysiol* 2014;125:658–66.
5. Colebatch JG. Mapping the vestibular evoked myogenic potential (VEMP). *J Vestib Res* 2012;22:27–32.
6. Rosengren SM, McAngus Todd NP, Colebatch JG. Vestibular-evoked extraocular potentials produced by stimulation with bone-conducted sound. *Clin Neurophysiol* 2005;116:1938–48.
7. Weber KP, Rosengren SM, Michels R, et al. Single motor unit activity in human extraocular muscles during the vestibulo-ocular reflex. *J Physiol* 2012;590:3091–101.
8. Todd NP, Rosengren SM, Aw ST, Colebatch JG. Ocular vestibular evoked myogenic potentials (OVEMPs) produced by air- and bone-conducted sound. *Clin Neurophysiol* 2007;118:381–90.
9. Manzari L, Curthoys IS. VEMPs: pathophysiology, method and results (short review). *Hear Bal Comm* 2021;19:224–30.
10. Singh NK, Firdose H. Characterizing the impact of advancing age on 500 Hz tone-burst evoked ocular-vestibular evoked myogenic potentials. *Eur Arch Otorhinolaryngol* 2021;278:4259–68.
11. Piker EG, Jacobson GP, McCaslin DL, Hood LJ. Normal characteristics of the ocular vestibular evoked myogenic potential. *J Am Acad Audiol* 2011;22:222–30.
12. Sandhu JS, George SR, Rea PA. The effect of electrode positioning on the ocular vestibular evoked myogenic potential to air-conducted sound. *Clin Neurophysiol* 2013;124:1232–6.
13. Vannson N, James C, Fraysse B, et al. Quality of life and auditory performance in adults with asymmetric hearing loss. *Audiol Neurootol* 2015;20(Suppl 1):38–43.
14. Çoban VK, Akın Öçal FC, Karaçaylı C, Satar B. Differences in bone conduction ocular vestibular evoked myogenic potentials to 500 Hz narrow band chirp stimulus and 500 Hz tone burst. *Auris Nasus Larynx* 2021;48:590–3.
15. Karaçaylı C, Akın Öçal FC, Çoban VK, Satar B. Normative data of ocular vestibular evoked myogenic potentials in response to chirp stimulus. *J Int Adv Otol* 2020;16:378–81.
16. Mat Q, Deggouj N, Duterme JP, et al. Using narrow band CE-chirps to elicit cervical vestibular evoked myogenic potentials. *Ear Hear* 2022;43:941–8.
17. Mat Q, Duterme JP, Tainmont S, Lelubre C, Manto M. Optimizing ocular vestibular evoked myogenic potentials with narrow band CE-chirps. *Ear Hear* 2021;42:1373–80.
18. Wang BC, Liang Y, Liu XL, et al. Comparison of chirp versus click and tone pip stimulation for cervical vestibular evoked myogenic potentials. *Eur Arch Otorhinolaryngol* 2014;271:3139–46.
19. Colebatch JG, Rosengren SM. Safe levels of acoustic stimulation: comment on '"effects of acoustic stimuli used for vestibular evoked myogenic potential studies on the cochlear function '". *Otol Neurotol* 2014;35:932–3.
20. Colebatch JG, Rosengren SM. Safe levels of acoustic stimulation for Vemps: comment on "sudden bilateral hearing loss after cervical and ocular vestibular evoked myogenic potentials". *Otol Neurotol* 2016;37:117–8.
21. Rosengren SM, Welgampola MS, Colebatch JG. Vestibular evoked myogenic potentials: past, present and future. *Clin Neurophysiol* 2010;121:636–51.

22. Jongkees LB, Maas JP, Philipszoon AJ. Clinical nystagmography. A detailed study of electro-nystagmography in 341 patients with vertigo. *Pract Otorhinolaryngol (Basel)* 1962;24:65–93.
23. Piker EG, Jacobson GP, Makowiec KF, Atabek PM, Krolewicz S. The medial canthus reference electrode is not electrically indifferent to the ocular vestibular evoked myogenic potential. *Otol Neurotol* 2018;39: e1069–77.
24. Govender S, Dennis DL, Colebatch JG. Vestibular evoked myogenic potentials (VEMPs) evoked by air- and bone-conducted stimuli in vestibular neuritis. *Clin Neurophysiol* 2015;126:2004–13.
25. Rosengren SM, Govender S, Colebatch JG. Ocular and cervical vestibular evoked myogenic potentials produced by air- and bone-conducted stimuli: comparative properties and effects of age. *Clin Neurophysiol* 2011;122:2282–9.
26. Govender S, Cheng PY, Dennis DL, Colebatch JG. Electrode montage and gaze effects on ocular vestibular evoked myogenic potentials (oVEMPs). *Clin Neurophysiol* 2016;127:2846–54.
27. Vanspauwen R, Wuyts FL, Krijger S, Maes LK. Comparison of different electrode configurations for the oVEMP with bone-conducted vibration. *Ear Hear* 2017;38:205–11.
28. Leyssens L, Heinze B, Vinck B, et al. 'Standard' versus 'nose reference' electrode placement for measuring oVEMPs with air-conducted sound: test-retest reliability and preliminary patient results. *Clin Neurophysiol* 2017;128:312–22.
29. Makowiec K, McCaslin DL, Jacobson GP, Hatton K, Lee J. Effect of electrode montage and head position on air-conducted ocular vestibular evoked myogenic potential. *Am J Audiol* 2017;26:180–8.
30. Zuniga MG, Davalos-Bichara M, Schubert MC, Carey JP, Janky KL. Optimizing ocular vestibular evoked myogenic potential testing for superior semicircular canal dehiscence syndrome: electrode placement. *Audiol Neurootol* 2014;19:239–47.
31. Phongsamart G, Wertsch JJ, Ferdjallah M, King JC, Foster DT. Effect of reference electrode position on the compound muscle action potential (CMAP) onset latency. *Muscle Nerve* 2022;25: 816–21.
32. Takahashi N, Robinson LR. The influence of the reference electrode on the compound muscle action potential of the flexor digiti minimi brevis. *Am J Phys Med Rehabil* 2010;89:570–5.
33. Murofushi T. Clinical application of vestibular evoked myogenic potential (VEMP). *Auris Nasus Larynx* 2016;43:367–76.
34. Ferm I, Lightfoot G. Further comparisons of ABR response amplitudes, test time, and estimation of hearing threshold using frequency-specific chirp and tone pip stimuli in newborns: findings at 0.5 and 2 kHz. *Int J Audiol* 2015;54:745–50.
35. Cheng PW, Murofushi T. The effects of plateau time on vestibular-evoked myogenic potentials triggered by tone bursts. *Acta Otolaryngol* 2001; 121:935–8.