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Original Article

The Vestibular Evoked Myogenic Potentials (VEMPs) test over the Trapezius Muscle: Neurophysiological Grounds in Muscle Extensor and Flexor Conditions

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BACKGROUND: The vestibular evoked muscle potentials (VEMPs) test provides information about the otolith organs and the vestibular nerves. The usefulness of VEMP responses related to the trapezius muscle in the evaluation of the vestibular system remains uncertain. The present study sought to compare VEMPs recorded over the trapezius muscle (tVEMP) in extensor and flexor conditions with cervical VEMP (cVEMP) responses and to evaluate the applicability of tVEMP.

METHODS: A total of 22 healthy male subjects, aged between 19 and 38 years, were included in the study. After the hearing test, cVEMP and tVEMP were applied to all participants. Cervical vestibular evoked myogenic potential was applied over the sternocleidomastoid muscle (SCM), and tVEMP was applied over the trapezius muscle in both extensor and flexor conditions.

RESULTS: The absolute latency of the tVEMP flexor condition P1 was found to be significantly longer than that of the cVEMP P1 ($P = .023$). There was no significant difference in N1 latencies across all 3 test methods ($P = .122$). The amplitudes of tVEMP P1-N1 in the flexor condition were found to be significantly lower than those of both cVEMP and tVEMP in the extensor condition ($P < .001$).

CONCLUSION: A 500 Hz tone burst stimulus can elicit VEMP responses from the trapezius, and tVEMP can be used as an alternative to cVEMP. It seems that a significant benefit of the tVEMP extensor test is that it can be employed as an alternative in cases where cVEMP is not feasible.

KEYWORDS: Electromyogram, extensor condition, flexor condition, myogenic potential, trapezius muscle

INTRODUCTION

Vestibular-evoked myogenic potentials (VEMPs) are electromyographic responses to sound, vibration, or electrical stimuli recorded from tonically contracted muscles known to be innervated by otolith organs.[1] Vestibular-evoked myogenic potentials are referred to as cervical VEMP (cVEMP) if measured through the sternocleidomastoid muscle (SCM), and ocular VEMP (oVEMP) if measured through the inferior oblique muscles. oVEMP, unlike cVEMP, is a contralateral reflex response recorded from the eye that is opposite the stimulated ear.[2]

In the literature, VEMP responses have been previously obtained from different muscle regions and in cases of abnormal muscle stimulation such as strabismus.[3-7] Publications on VEMP responses from the trapezius muscle are limited.[8,9] In a study conducted in healthy individuals, both cVEMP and tVEMP were applied. In this study, tVEMP was applied in the extensor condition. Also, recordings were taken from the upper trapezius region.[8] That is, detailed neurophysiological grounds of the tVEMP have not been described so far. cVEMP recording in some patients may not be obtained since an appropriate muscle contraction is not achieved. It is also difficult to record cVEMP responses in patients with head and neck problems. In patients with functional neck dissection without vestibular complaints, cVEMP responses can be obtained. It has been reported that it is not clear whether these abnormalities are due to functional neck dissection or the vestibular system.[10] Additionally, patients sometimes report difficulty contracting the

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SCM and experience pain in the neck with the VEMP test. Alternative approaches for assessing saccular function are necessary, particularly in cases where sufficient contraction of the SCM cannot be achieved. The trapezius muscle is easier to contract than the SCM. Therefore, in this study, the aim was to compare VEMP responses of the trapezius muscle (tVEMP) in extensor and flexor conditions with cervical VEMP (cVEMP) responses and to evaluate the applicability of the tVEMP test.

The hypotheses are:

H_0: The tVEMP test cannot be used as an alternative to the cVEMP test in the extensor condition.

H_1: The tVEMP test can be used as an alternative to the cVEMP test in the extensor condition.

METHODS

Subjects

Written informed consent was obtained from all participants. This study was approved by the Ethics Committee of University of Health Sciences (Decision No: 2020-122, Date: April 19, 2020). The study included 22 healthy individuals aged 19 to 38 who agreed to participate in the study. An otologic and otoneurologic examination of all individuals was performed by an otolaryngologist. Pure-tone air and bone conduction thresholds were measured between 250 Hz and 8000 Hz in order to confirm that the individuals had normal hearing. Individuals with hearing thresholds better than 15 dB were included in the study. Additionally, the middle ear status of all participants was evaluated using a 226 Hz probe tone (Maico MI 44, MAICO Diagnostics, Berlin, Germany). Only individuals who presented with a Type A tympanogram in the tympanometric assessment were included in the study. To rule out possible peripheral and central pathologies, spontaneous nystagmus, gaze, head shaking, head impulse, and positional tests were performed with Frenzel glasses on videonystagmography.

Cervical Vestibular Evoked Myogenic Potential and Trapezius Vestibular Evoked Myogenic Potential

Both the cVEMP and tVEMP tests were completed monaurally at 95 dB nHL with a 500 Hz tone burst stimulus. Data were collected with an Interacoustic Eclips EP 25 (Assens, Denmark) brand device. Sound stimuli were provided through insert earphones (Ear Tone ABR 3A, USA). The individuals were told to stand upright in a comfortable position. After providing detailed information about the test, the skin was cleaned. In the cVEMP test, the ground electrode was placed on the forehead, the active electrode was placed on the upper 1/3 of the SCM, and the reference electrode at the sternoclavicular junction (Figure 1). In the tVEMP test, the ground electrode was placed on the forehead, the active electrode was placed 10 cm below the C7 level, 1 cm lateral to the vertebra, and the reference electrode on the back of the neck at the C7 level (Figure 1). The requisite consent for electrode placement, patient position, and cVEMP and tVEMP wave samples was obtained from the healthy individual for publication for educational purposes, as illustrated in Figures 1, 2, 3, and 4. Electrode impedances were below 5 kΩ. Responses were recorded ipsilaterally. The same stimulus parameters were used for both test methods. Stimulus parameters: stimulus type: rise/fall time 2:0:2 cycle of 500 Hz tone burst; stimulus level: 95 dB nHL; rate: 5.1; polarity: rarefaction; number of sweeps: 200; number of channels: 2; high-pass filter: 10 Hz; low-pass filter: 1000 Hz.

MAIN POINTS

- It was possible to obtain reliable trapezius vestibular evoked muscle potential responses in the extensor condition.
- Trapezius vestibular evoked muscle potential (tVEMP) in the extensor condition could be used as an alternative to cervical vestibular evoked myogenic potential (cVEMP).
- The direction of the P1-N1 waves (negative/positive) in tVEMP in the extensor condition of the trapezius differed from that of the cVEMP waves (positive/negative).
- The direction of the P1-N1 waves (positive/negative) in tVEMP in the flexor condition of the trapezius was consistent with that observed in cVEMP waves.

Procedure

Firstly, the cVEMP test was applied to all individuals. Then, the tVEMP measurements were completed in the right and left ear over the trapezius muscle, first in the extensor condition and then in the flexor condition. All tests were completed at 95 dB nHL with a 500 Hz tone burst stimulus. The cVEMP and tVEMP electromyogram (EMG) muscle activities in the extensor condition were in the range of 50-150 µV. In the flexor condition of the trapezius muscle, muscle activity was fixed in the range of 30-80 µV to record responses. In the extensor condition, the patient's arm with the elbow in a flexed position, was elevated to a point just below the level of the sternum and then moved towards the back. This resulted in muscle activity reaching a range of 50-150 µV in the EMG. In the flexor condition, the trapezius muscle was activated by elevating the patient's arm with the elbow in flexion to a position just below the level of the chest. This position was maintained for a period of time sufficient to allow for the measurement of muscle activity, which reached a level between 30 and 50 µV in the EMG. P1 and N1 absolute latencies, P1-N1 amplitude, and interaural amplitude asymmetry ratios (IAR) were compared via cVEMP and tVEMP tests in the extensor and flexor conditions.

Statistical Analysis

The Shapiro-Wilk test was used as a normality test. The Friedman test was used for repeated measurements of non-normally distributed data. Continuous data are expressed as mean ± SD and median (min-max). Categorical data are expressed as percentages. The McNemar test was used for the comparison of categorical data in dependent groups. Any *P*-value less than .05 was considered significant.

Power Analysis

A power analysis was conducted using the reference by Çoban et al[11] (2021) to determine the required sample size for this study. Based on a statistical power of 95%, a significance level of 0.05, and an effect size of 2.8460711 for P1 latency, 3.3534634 for N1 latency, and 0.7789006 for P1-N1 amplitude, the required sample size was calculated to be 21 participants using the Wilcoxon signed-rank test. G*Power 3.1(Heinrich-Heine-Universität Düsseldorf; Düsseldorf, Germany) was used for the analysis.

Figure 1. Demonstration of electrode placement for trapezius vestibular evoked myogenic potential and cervical vestibular evoked myogenic potential in a healthy individual.

RESULTS

This study was completed with 22 healthy male subjects (44 ears) aged 19 to 38 years. cVEMP responses were obtained in 43 ears, tVEMP in the extensor condition in 39 ears, and tVEMP in the flexor condition in 10 ears (Table 1).

While there was no significant difference in biphasic P1-N1 wave obtainability between cVEMP and tVEMP in the extensor condition ($P = .219$), there was a significant difference between both cVEMP and tVEMP in the flexor condition and also between tVEMP in the extensor condition and tVEMP in the flexor condition ($P < .001$) (Table 1).

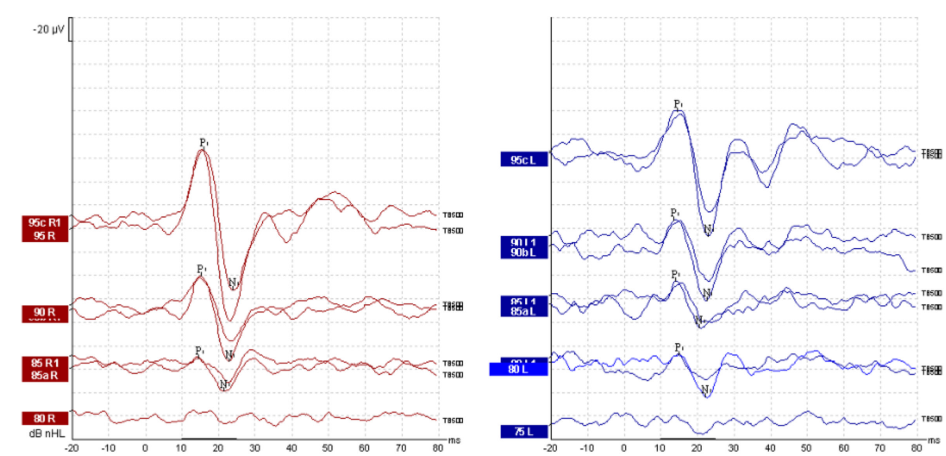

Figure 2. P1-N1 waveform obtained from cervical vestibular evoked myogenic potential with a tone burst 500 Hz stimulus in a healthy individual.

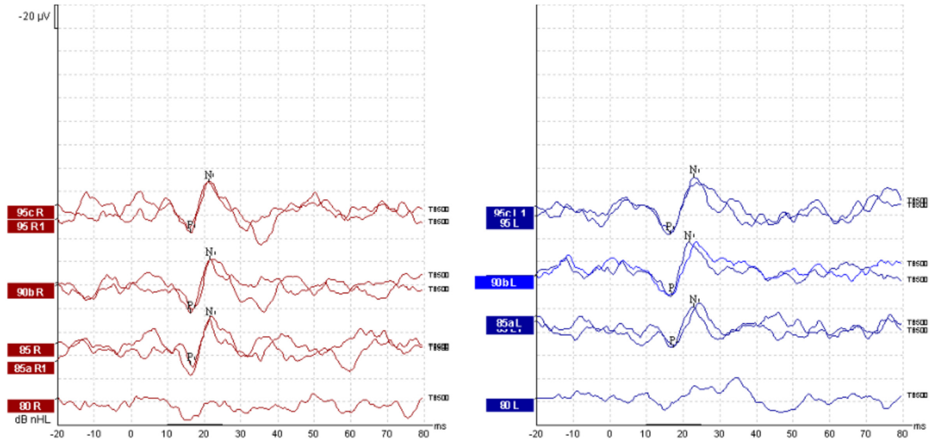

Figure 3. P1-N1 waveform obtained from trapezius vestibular evoked myogenic potential in extensor condition with tone burst 500 Hz stimulus in a healthy individual.

The cVEMP waveform in healthy subjects and the tVEMPs in the extensor and flexor conditions are shown in Figures 2, 3, and 4, respectively.

It was observed that the direction of the biphasic P1-N1 waves (positive/negative) obtained via the cVEMP test was different from those obtained via the tVEMP test in the extensor condition, whereas the direction of the waves (positive/negative) seen in the tVEMP test in the flexor condition was the same (respectively, Figures 2, 3, and 4).

The absolute latency of tVEMP P1 in the flexor condition was observed to be significantly longer than that of cVEMP P1 ($P=.023$). There was no significant difference between the cVEMP P1 absolute latency and the tVEMP P1 absolute latency in the extensor condition and between the tVEMP P1 absolute latency in the extensor condition and the tVEMP P1 absolute latency in the flexor condition (Table 2).

There was no significant difference in N1 latencies across all 3 test methods ($P=.122$). When the groups were compared in terms of P1-N1 amplitudes, tVEMP P1-N1 amplitudes in the flexor condition was significantly lower than both cVEMP and tVEMP in the extensor condition ($P < .001$).

There was no significant difference among the 3 test methods in terms of IAR ($P=.834$).

When the final thresholds obtained in all 3 test methods were compared, a significant difference was found between cVEMP and tVEMP in the flexor condition ($P=.001$). The tVEMP threshold in the flexor condition was significantly higher than that of cVEMP, while there was no significant difference between the other groups (Table 2).

DISCUSSION

The results of this study showed that the direction of the biphasic P1-N1 waves (positive/negative) obtained as a result of the cVEMP test was different from that of the waves (negative/positive) obtained from the tVEMP test in the extensor condition of the trapezius muscle. Conversely, the direction of the waves (positive/negative) in tVEMP in the flexor condition of the trapezius exhibited a consistent polarity. Wu et al[13] recorded VEMPs in response to 500 Hz tone burst stimulation through the SCM and splenius capitis.[12] They found that the P1-N1 VEMP wave polarity obtained in the SC was inversely aligned with that observed in the SCM. They suggested that this was due to the flexor and extensor status of the muscles in the human neck.[13] Ferber-Viar et al[8] compared VEMP responses recorded from the trapezius muscle and SCM. Upon examination of the waveforms associated with tVEMP in the aforementioned study, it was observed that they were consistent with this study's findings. It is widely accepted that the response from the ipsilateral SCM has an inhibitory effect, as evidenced by the superior recording of cVEMP in the activation state of the SCM. Accordingly, it was hypothesized that while the response

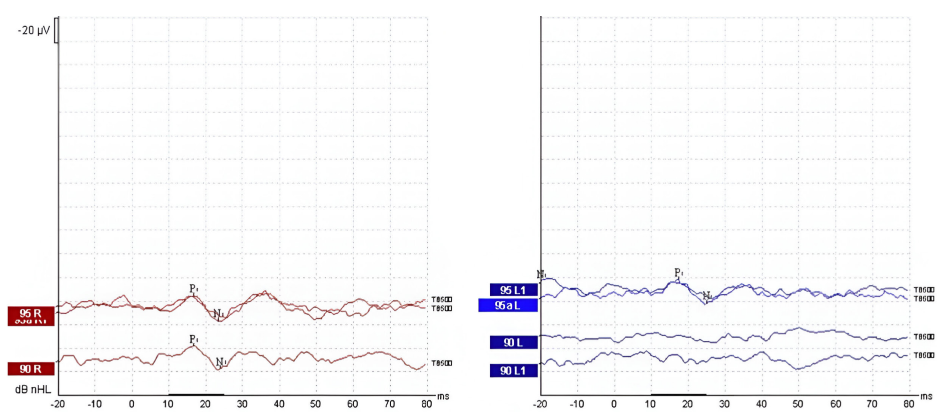

Figure 4. P1-N1 waveform obtained from trapezius vestibular evoked myogenic potential in the flexor condition with tone burst 500 Hz stimulus in a healthy individual.

Table 1. Incidences of Biphasic P1-N1 Waves of Cervical Vestibular Evoked Myogenic Potential and Trapezius Vestibular Evoked Myogenic Potential in Extensor and Flexor Conditions

		cVEMP		Total	*P**
		Absent	Present		
tVEMP in extensor condition	Absent	0 (0%)	5 (100%)	5 (11.36%)	.219
	Present	1 (2.56%)	38 (97.44%)	39 (88.64%)	
tVEMP in flexor condition	Absent	1 (2.94%)	33 (97.06%)	10 (22.73%)	<.001
	Present	0 (0%)	10 (100%)	1 (77.27%)	

cVEMP, cervical vestibular evoked myogenic potential; tVEMP, trapezius vestibular evoked myogenic potential.
*McNemar test.

from the ipsilateral trapezius muscle (in the extensor condition) is an excitatory neural activity. These findings suggest that the wave responses from the ipsilateral trapezius (flexor condition) may be inhibitory, as is the response from the ipsilateral SCM.

In the extensor condition of the trapezius muscle, the tVEMP P1-N1 waves were observed in 39 ears, whereas they were observed in only 10 ears in the flexor condition. The trapezius muscle, as a large postural muscle, exhibits different functional characteristics depending on its contraction state.[14] In the extensor condition, the trapezius muscle is actively engaged, leading to higher muscle tone and increased activation of the vestibulospinal pathways. This heightened muscle activity likely facilitates the generation of measurable VEMP responses, as the inhibitory mechanisms mediated by the vestibular system become more pronounced. This may explain the high success rate of tVEMP in the extensor condition. In contrast, in the flexor condition, the trapezius muscle is in a more relaxed state with minimal contraction. This reduced muscle activity may hinder sufficient activation of the vestibulospinal pathways, resulting in weaker or undetectable VEMP responses. The low success rate in the flexor condition could be attributed to insufficient muscle tone and the lack of necessary conditions for generating inhibitory responses. Additionally, the flexor position may alter the mechanical properties of the muscle, making it less sensitive to vestibular stimulation. Furthermore, the influence of muscle mass and individual anatomical variations should not be overlooked. In this study, it was observed that tVEMP responses in the flexor condition were more frequently detected in individuals with higher cVEMP amplitudes. This suggests that individuals with larger muscle mass or more responsive muscles may still produce measurable signals even under suboptimal conditions. This finding supports the hypothesis that muscle size and activation level play a critical role in the generation of VEMP responses.

Mohamed Ali et al[15] compared cVEMPs recorded from SCM and SC in young and older patients as well as in patients with Parkinson's disease. They did not find any change in the incidence and parameters of cVEMPs recorded from SC in older individuals. However, they found both a change in parameters and a lower incidence in cVEMPs recorded from the SCM. The SC is more readily contractible than the SCM, which was hypothesized allows for more efficient application of the test. Although the tVEMP test was performed on a young population in this study, it was hypothesized that the more facile contraction of the trapezius muscle in comparison to the SCM will diminish the occurrence of false results pertaining to potential vestibular pathologies in older individuals with restricted neck movement. With aging, an increase in muscle stiffness and tone, along with a decrease in elasticity, is observed in both the SCM and trapezius muscles.[16] The motor innervation of both muscles is provided by the XIth cranial nerve (accessory nerve).[17] Kocur et al[18] observed a greater decline in muscle contraction with aging in the SCM muscle. According to the study findings, aging was associated with a more pronounced decrease in elasticity and a greater increase in stiffness in the SCM muscle. Specifically, age accounted for 53% of the variance in elasticity and 28.5% of the variance in stiffness of the SCM muscle. In contrast, these proportions were lower for the trapezius muscle, with age explaining 13% of the variance in elasticity and 22% of the variance in stiffness. These data indicate that the SCM muscle experiences a greater loss of elasticity and an increase in stiffness with aging, suggesting a more significant decline in contraction capacity compared to the trapezius muscle.[18] Based on feedback from the study participants, the trapezius muscle requires less specific movement and can be effectively contracted by elevating the arm and positioning it slightly posteriorly. In this context, the tVEMP test may serve as a more reliable alternative for vestibular function assessment in elderly individuals with limited cervical mobility by reducing false-negative results due to insufficient muscle contraction.

In this study, no significant difference was found in N1 absolute latencies among the 3 test methods. However, the P1 absolute latency in the flexor condition of tVEMP was found to be significantly longer compared to the P1 absolute latency of cVEMP. While the P1-N1 absolute latencies of tVEMP in the extensor condition were similar to those of cVEMP, the P1-N1 amplitudes of cVEMP were measured

Table 2. Comparison of Biphasic P1-N1 Wave Absolute Latency, Amplitude, and Interaural Amplitude Asymmetry Ratio (IAR) Among Cervical Vestibular Evoked Myogenic Potential, Trapezius Vestibular Evoked Myogenic Potential in Extensor and Flexor Conditions

	cVEMP		tVEMP in Extensor Condition		tVEMP in Flexor Condition		Test Stats.*	*P*
	Mean ± SD	Median (min-max)	Mean ± SD	Median (min-max)	Mean ± SD	Median (min-max)		
P1 latency	16.27 ± 1.46	15.83[a] (14.33-18.33)	17.43 ± 1.18	17.17 (16-19.33)[ab]	20.23 ± 3.5	19.5 (15.33-25.33)[b]	7.538	0.023
N1 latency	24.67 ± 1.69	25 (21.33-26.67)	24.47 ± 2.55	23.67 (21.33-29.67)	28.97 ± 4.36	28.84 (23.33-34.33)	4.2	0.122
P1-N1 amplitude	89.31 ± 65.63	64.87 (41.43-261)[a]	56.2 ± 21	43.21 (39.18-92.34)[a]	19.96 ± 6.01	20.27 (12.55-32.11)[b]	15.8	<0.001
IAR	0.12 ± 0.06	0.16 (0.04-0.16)	0.09 ± 0.09	0.04 (0.02-0.2)	0.13 ± 0.12	0.08 (0.03-0.29)	0.364	0.834
Threshold (dB nHL)	85 ± 4.33	85 (80-90)[a]	87.78 ± 3.63	85 (85-95)[ab]	93.33 ± 2.5	95 (90-95)[b]	13.231	0.001

There is no statistically significant difference between the groups that share the same letters in the same row.
cVEMP, cervical vestibular evoked myogenic potential; IAR: Interaural Amplitude Asymmetry Ratio; tVEMP, trapezius vestibular evoked myogenic potential.
*Friedman test.

to be higher than those of tVEMP in both extensor and flexor conditions. A previous study conducted on 16 healthy individuals with normal hearing reported that the P1-N1 latencies recorded from the SCM were significantly shorter, and the amplitudes were lower compared to those obtained from the trapezius muscle.[8] In that study, both tVEMP and cVEMP were applied in the extensor condition. Different results were observed in terms of both latency and amplitude compared to this study. It was believed that there are several possible reasons for these differences in latency and amplitude when compared to this study. First, this study was conducted exclusively with male participants and included a larger sample size. Second, while the previous study used 0.1 ms click stimuli, this study used 500 Hz tone burst stimulation. Third, the electrode placement for tVEMP recordings differs; this was recorded from a different region of the trapezius muscle (C7 level), introducing an alternative measurement approach. Fourth, the previous study required participants to perform isometric muscle contraction only in a sitting position, whereas in this study, tVEMP measurements were conducted in both extensor and flexor muscle contraction conditions. Considering these methodological differences, this study not only demonstrates that tVEMP could serve as an alternative test method but also provides a new perspective on how vestibular responses vary under different muscle contraction conditions. One of the most significant novel findings of this study is the distinct difference observed in tVEMP responses in the flexor condition, where P1 latencies were significantly prolonged, and amplitudes were reduced. This finding suggests that the type of muscle contraction has a notable impact on tVEMP characteristics, a factor that was not emphasized in the previous study.

In this study, cVEMP responses were obtained more frequently than tVEMP responses in the same individuals. However, this difference was not found to be statistically significant. This may be due to various physiological and methodological factors. Although cVEMP responses were obtained in all individuals, there have been reports in the literature where cVEMP responses could not be obtained even in healthy individuals.[19,20] tVEMP responses obtained from the trapezius muscle may be more variable due to different activation levels of its segments and electrode placement. Additionally, anatomical differences in the SCM and trapezius muscles among individuals may have contributed to the lower rate of tVEMP responses compared to cVEMP.

The reliability of the tVEMP is demonstrated by the recordability and reproducibility of the test in the extensor condition. It would be beneficial to investigate whether there are pattern differences in tVEMP in flexor and extensor conditions in patients with various pathological conditions. It is hypothesized that investigating both inhibitory and excitatory nerve fibers of the VEMP pathway, in contrast to cVEMP, may offer an additional advantage.

Limitation of study

A significant limitation of this study is that the tVEMP was conducted on male subjects exclusively. It is believed that future studies on both male and female subjects and patient groups will provide a more comprehensive evaluation of the utility of tVEMP.

CONCLUSION

The results demonstrate that tVEMP responses, particularly in the extensor condition, can be reliably obtained. The findings substantiate the hypothesis that tVEMP in the extensor condition can serve as an alternative to cVEMP. The distinction in the polarity of P1-N1 waves in tVEMP extensor and flexor conditions is a notable observation that merits further investigation in pathological contexts.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of University of Health Sciences (approval number: 2020-122, date: April 19, 2020).

Informed Consent: Written informed consent was obtained from participants who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – B.S.; Design –B.S., E.K., C.K.; Supervision –B.S.; Resources – E.K., C.K.; Materials – E.K., C.K.; Data Collection and/or Processing – E.K., C.K.; Analysis and/or Interpretation – C.K.; Literature Search – E.K., C.K.; Writing Manuscript – B.S., E.K., C.K.; Critical Review – B.S.; Other –B.S., E.K., C.K.

Declaration of Interests: The authors declare that they have no competing interests.

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