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LONG TERM VESTIBULAR EFFECTS OF BLAST TRAUMA

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ABSTRACT

OBJECTIVE: In this study, the presence of dizziness in the late period was investigated in patients working in the Armed Forces who exposed to blast trauma with a test battery consisting of cervical and ocular vestibular evoked myogenic potentials(cVEMP and oVEMP) and dizziness handicap inventory(DHI).

METHODS: Twenty-two healthy adult volunteers(44 healthy ears)and 25 military personnel (43 patient ears) who had blast trauma were included in the study.The cVEMP and oVEMP tests were applied to the control and patient groups.The patient group also filled in the Dizziness Handicap Inventory(DHI).

RESULTS: The mean score of the DHI of the patient group was 14.80±23.38. In cVEMP and oVEMP tests there was no significant difference in comparison of P1 latency, N1 latency and P1N1 amplitude between control and patient groups.

CONCLUSION: It was observed that the functions of otolith organs were not affected in the late period after blast trauma.

Keywords: hearing loss, vestibular evoked myogenic potentials (VEMP), dizziness

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INTRODUCTION

Primary blast injuries typically affect the auditory system. High pressure with the general blast effect can trigger hearing loss which can be conductive, sensorineural, or mixed type. In reports in literature of the effects of blast trauma on the auditory system, there is hearing loss of any type and level in approximately 60% of patients.[1] Hearing losses can vary from a mild degree to a very advanced degree. Just as blast effect can affect the outer ear, there may also be tympanic membrane perforations of various dimensions in the middle ear, and ossicle chain ruptures and fractures.[2,3] In the cochlea, mechanical damage is seen because of excessive force applied on basilar membranes (BM) with the blast effect. This can lead to separation of the support cells on the BM from inner and outer hair cells. In addition, it can cause ruptures resulting in the mixing of perilymph and endolymph causing changes in the integrity of the tight cell connections in the reticular lamina, changes in membrane permeability or in the reticular lamina, and changes in the ionic environment of cochlear fluid. Loss of hair cells can be induced by the blast. Greater damage has been seen in outer hair cells than in inner hair cells. This damage in the cochlea is more evident in the basal section (at high frequencies) than in the apical section.[3,4] Perilymph fistula can be observed originating from rupture of the round window.

The otolith organs are formed from utricles and saccules which contribute to postural stability by providing sensory input related to changes in gravity and linear acceleration. Saccules perceive linear acceleration in the vertical plane, whereas utricules are localised horizontally and perceive linear acceleration in the horizontal plane. Tests that have been developed to measure the otolith function have become more important in recent years. Cervical vestibular evoked myogenic potentials (cVEMP) measure saccular and inferior vestibular nerve function, and ocular vestibular evoked myogenic potentials (oVEMP) measure the vestibular response from the utricle through the superior vestibular nerve.[5]

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In addition to blast trauma affecting the cochlea, it also affects the vestibular system because of the close anatomic proximity. It is thought that there could be an effect in the utricle and saccule because of the proximity to the stapes in particular. The damage forming in the utricle and saccule following the blast has been shown histologically in literature.[6,7] However, this is a subjective clinical complaint in patients and the results of publications in literature related to observation in objective tests are conflicting. The aim of this study was to evaluate long-term dizziness subjectively with questionnaires and objectively with electrophysiological tests in patients with sensorineural hearing loss following exposure to blast trauma while serving in the Armed Forces.

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MATERIAL-METHODS

Approval for the study was granted by the Medical and Health Sciences Research Committe and the Non-Interventional Clinical Research Ethics Committee (decision no:20/22, dated:12.02.2020). All procedures were applied in compliance with the Helsinki Declaration. The study was planned as a case-control study. The sample size was calculated using G*power program to provide 0.95 power and 0.05 significance level. The patient group was formed of 25 military personnel (43 affected ears) who had experienced blast trauma while serving in the Armed Forces, and a control group was formed of 22 healthy adult volunteers (44 healthy ears). All of the patient group was injured by hand-made explosives. Although hearing loss developed immediately after the explosion, they admitted to the ENT clinic in the late period due to intracranial and orthopedic injuries. Informed consent for voluntary participation in the study was provided by all the study participants.

The control group was formed of healthy subjects age and gender-matched to the military personnel patients who presented at the hospital because of blast trauma.

The inclusion criteria for the patient group were defined as:

1) No history of otological (ear membrane perforation, ear surgery, chronic otitis), neurological, or ophthalmological problems,
2) Diagnosed with sensorineural hearing loss because of blast trauma.

The inclusion criteria for the control group were defined as:

1) Normal results of otoscopic examination of both ears and pure tone average (PTA) of better than 20dB,
2) Type A tympanogram and the presence of normal acoustic reflex,
3) No determination of any otological or neurological problems.

Following the otoscopic examination, the control group was applied with pure tone audiometry, tympanometry, acoustic reflex, and cVEMP and oVEMP tests with both Tone-

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Burst (TB) and Narrow Band (NB) Level Specific (LS) CE-Chirp stimuli. In addition to these examinations, the patient group also completed the Dizziness Handicap Inventory (DHI).

Pure Tone Audiometry

Air conduction thresholds at 125-8000 Hz and bone conduction thresholds at 250-4000 Hz were measured with the same device (AC40, Interacoustic, Denmark). Supra-aural TDH 39 earphones were used in the measurements. The pure tone average was calculated as the average of the 500, 1000, 2000, and 4000 Hz measurements.

Dizziness Handicap Inventory (DHI)

The DHI aims to determine the change in the quality of life of patients with complaints of dizziness.[8] The scale comprises 25 items related to the physical, functional, and emotional status of patients. High points scored on the scale indicate that the quality of life of the patient is more negatively affected. Validity and reliability studies of the Turkish version of the inventory have been conducted. [9]

Cervical Vestibular Evoked Myogenic Potential (cVEMP) and Ocular Vestibular Evoked Myogenic Potential (oVEMP) recordings

The tests were performed in a quiet room with the patient seated. The Interacoustic Eclipse EP 15 device (Interacoustics Eclipse EP15; Assens, Denmark) and insert earphones (Ear tone ABR 3A; 3M, Minneapolis, MN, USA) were used in the tests. The device was calibrated by technicians licensed according to the ISO 389-6 standards. For the cVEMP recording, an active (non-inverting (+)) electrode was placed on the sternum, reference (inverting (-)) electrodes were placed on the section adjoining the upper third of the two sternocleidomastoid (SCM) muscles, and the ground electrode was placed on the vertex (Ambu®Neuroline ™ 720; Ambu, Denmark). Effective contraction of the SCM muscle was obtained by turning the head away from the side of the ear being tested, and observing the visual feedback of the software throughout the test. As the P13N23 amplitude is affected by SCM

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muscle contraction, the study subjects were informed of the visual feedback obtained from the software during the EMG recording to keep the muscle activity at a stable level. To eliminate the effect of muscle fatigue, the NB LS CE-chirp and TB stimuli were applied randomly.

For the oVEMP recording, the reference electrodes (inverting) were placed 1 cm below both eyelids (over the inferior oblique muscle), the active (non-inverting (+)) electrode was placed on the chin and the ground electrode on the forehead (Ambu®Neuroline™ 720; Ambu, Ballerup, Denmark). The subjects were instructed to look continuously at a fixed point at approximately 30° upwards and a distance of 60cm. The impedance of the electrodes was set at <5 kOhm. Responses formed to stimuli at 500 Hz tone-burst (TB) and 500 Hz Narrow Band Level Specific Claus Elberling Chirp (NB LS CE-Chirp) (360-720 Hz) were recorded separately for each ear. For the 500 Hz TB, the rise, plateau, and fall times were 2-2-2 ms. The stimulus time for 500 Hz NB CE-Chirp between 360-720 Hz stimuli (Up chirp) was 9 msn. The recordings for both stimuli were started at 95 dB nHL, and were reduced by 5 dB nHL until the threshold was determined.

cVEMP was defined as a biphasic P1N1 (P13N23) wave, characterised by positive polarity in approximately the 13th millisecond (P13) and negative polarity in approximately the 23rd millisecond (N23). oVEMP was defined as negative polarity in approximately the 10th millisecond (N10) and positive polarity in approximately the 16th millisecond (P16). When the same form and latency was obtained when the tests were repeated twice, this was evaluated as a response. The EMG signals were amplified (x10,000) and filtered between 10-1000 Hz. The stimulus rate was set as 5.1 / sn, analysis duration 55 ms, and polarity as rarefaction. A total of 200 stimuli were obtained on average. To normalise the raw VEMP amplitudes for cVEMP, the rectified EMG was taken into consideration. For muscle activity, the rectified muscle signal (RMS) was kept at 20-200 µV during the recording.

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Measurements were taken of P1 latency, N1 latency, P1N1 amplitudes, and thresholds for each stimulus for 43 affected ears and 7 non-affected ears in the patient group, and for 44 healthy ears in the control group.

Statistical Evaluation

Data obtained in the current study were analyzed statistically using SPSS vn. 22 software (SPSS Inc., Chicago, IL, USA).Descriptive statistics were stated as mean ± standard deviation (SD), median, minimum- maximum, and interquartile range (IQR) values. In the comparisons between the hearing threshold frequencies of the affected ears in the patient group, the Wilcoxon Signed Rank test with Bonferroni Correction was used. In the comparisons of the hearing frequency thresholds between the affected and non-affected ears in the patient group, the Student's t-test was applied to data showing normal distribution and the Mann Whitney U-test to data that did not show normal distribution. These two tests according to the parametric assumptions were also applied to the comparisons between the patient and control groups in respect of the cVEMP and oVEMP P1 latency, N1 latency, and P1N1 amplitude for each stimulus. A value of $p<0.05$ was accepted as statistically significant.

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RESULTS

Evaluation was made of 43 ears affected by blast trauma in 25 patients and 44 healthy ears of 22 healthy control group subjects. The mean age of the subjects was 28.68±7.25 years (range, 20-47 years) in the control group, and 26.44±7.25 years (range, 20-48 years) in the patient group. No significant difference was determined between the groups in respect of age (p=0.222).

In the patient group, the mean time since the blast trauma was 41.16±16.75 days (range, 22-65 days). The ears were affected bilaterally in 18/25 patients and unilaterally in 7/25 (4 left ear, 3 right ear). The mean DHI score of the patient group was 14.80±23.38 (range, 0-88).

The pure tone averages, threshold values (dB HL) at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz , 6000 Hz, and 8000 Hz frequencies of the 43 affected ears in the patient group are shown in **Table 1.**

In the comparisons of the 43 affected ears in the patient group at low frequencies (250-500 Hz), mid frequencies (1000-2000 Hz) and high frequencies (4000- 6000- 8000 Hz), statistically significant difference was observed between the 3 groups (Friedman test, p=0.000). In the within group comparisons, there was no significant difference between the hearing thresholds at low and mid frequencies, and there was determined to be a significant difference between the low and high frequencies and between the mid and high frequencies (Wilcoxon Signed Rank test with Bonferroni Correction- low- mid:p=0.154, low-high: p=0.000, mid-high: p=0.000). The hearing thresholds at high frequencies were found to be significantly high in the ears affected by blast trauma**.**

The comparisons of the pure tone averages, and hearing thresholds at low, mid, and high frequencies of the affected and non-affected ears in the patient group are shown in **Table 2.**

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No statistically significant difference was determined between the two groups of affected and non-affected ears in the patient group in respect of hearing thresholds at low frequencies (p=0.713). A statistically significant difference was determined in both groups between mid and high frequencies (p=0.001, p=0.000, respectively). The difference in pure tone average between the groups was statistically significant (p=0.000).

In all the 44 healthy control group ears, cVEMP and oVEMP responses were obtained with both 500 Hz TB and 500 hzNB LS CE-chirp stimulus. In the patient group, cVEMP response was not obtained in 3 of 43 affected ears (6.9%) with both 500 Hz NB LS CE-Chirp stimulus and 500 Hz TB stimulus. In 5/43 ears (11.6%), no 500 HZ TB oVEMP response was obtained, and in 3/43 (6.9%) no 500 Hz NB LS CE-Chirp oVEMP was obtained. So there were 2 people who did not have 500 Hz TB oVEMP response, but have a 500 Hz NB LS CE-Chirp oVEMP response.

The cVEMP responses obtained with 500 Hz TB stimulus in the patient and control groups are shown in **Figure 1**. The comparisons of the 500 Hz TB cVEMP P1 latency, N1 latency, and P1N1 amplitude values between the patient and control groups are shown in **Table 3.** No statistically significant difference was determined between the patients and control groups in respect of the P1 latency, N1 latency, and P1N1 amplitude values in the cVEMP test applied with 500Hz TB stimulus (p:0.467, p:0.925, p:0.066, respectively).

The cVEMP responses with 500 Hz LS CE-Chirp stimulus of the patient and control groups are shown in **Figure 2.**

The comparisons of the 500 Hz LS CE-Chirp cVEMP P1 latency, N1 latency, and P1N1 amplitude values between the patient and control groups are shown in **Table 4.**

No statistically significant difference was determined between the patients and control groups in respect of the P1 latency, N1 latency, and P1N1 amplitude values in the cVEMP test applied with 500Hz NB LS CE-Chirp stimulus (p:0.576, p:0.993, p:0.078, respectively).

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The oVEMP responses obtained with 500 Hz TB stimulus in the patient and control groups are shown in **Figure 3.**

The comparisons of the 500 Hz TB oVEMP P1 latency, N1 latency, and P1N1 amplitude values between the patient and control groups are shown in **Table 5.**

No statistically significant difference was determined between the patients and control groups in respect of the P1 latency, N1 latency, and P1N1 amplitude values in the oVEMP test applied with 500Hz TB stimulus (p:0.484, p:0.933, p:0.289, respectively).

The oVEMP responses with 500 Hz NB LS CE-Chirp stimulus of the patient and control groups are shown in **Figure 4.**

The comparisons of the 500 Hz NB LS CE-Chirp oVEMP P1 latency, N1 latency, and P1N1 amplitude values between the patient and control groups are shown in **Table 6.**

No statistically significant difference was determined between the patients and control groups in respect of the P1 latency, N1 latency, and P1N1 amplitude values in the oVEMP test applied with 500 Hz NB LS CE-Chirp stimulus (p:0.081, p:0.062, p:0.418, respectively).

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DISCUSSION

The ear is one of the most frequently injured organs following blast trauma. In literature, it has been reported that sensorineural, conductive, or mixed type hearing losses are seen with the effect of blast trauma. However, there are very few studies related to whether or not there is any change in the vestibular system with blast effect, and the results of those studies are extremely variable. The aim of the current study was to evaluate late-term dizziness subjectively and objectively in patients who had developed sensorineural hearing loss as a result of exposure to an explosion while serving in the Turkish Armed Forces.Objective assessment was done with cVEMP and oVEMP. Although the study results showed that there was no significant change in otolith function with blast effect, there was seen to be an absence of cVEMP and oVEMP responses in some patients. A high DHI score was obtained by very few patients.

A blast (explosion) is the energy which generally occurs with the rapid transformation of solids or liquids to gas. Gas molecules heat up rapidly and move more quickly than the speed of sound with high pressure. Pressurised gas fills the same volume as liquid or solids. The high pressure area expands and an excessive pressure peak is reached which is known as shock wave. Low pressure, which is known to be a drop in atmospheric pressure, follows the shock wave, and an overheated blast wind is formed.[1] Blast injuries can be classified in 5 different categories, as primary, secondary, third, fourth, and fifth-degree injuries. The ear is within primary blast injuries and damage or injuries develop as a result of excessive pressure or the low pressure wave itself.

In literature, the hearing results following blast trauma show great variability. This can most probably be attributed to the proximity of the individual to the blast, the type and amount of explosive used, and the environment in which the explosion occurred. A 2017 study reported that hearing loss was sensorineural in 30% of cases exposed to blast trauma, mixed type in 55%,

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and conductive type in 15% .[10] In the current study cases, with TM perforation and ossicle chain pathologies were not included as these can greatly inhibit the response to VEMP tests.[11]

Cervical VEMP (cVEMP) showing the function of the ipsilateral saccule and inferior vestibular nerve, and ocular VEMP (oVEMP) showing the function of the contralateral utricle and superior vestibular nerve, are non-invasive electrophysiological tests. [5, 12,13]

When traditional acoustic stimuli are used, such as click, TB, and tone-pip, different neural regions along the cochlea cannot be stimulated at the same time. However, the chirp stimulus has been designed to compensate for the time delay in peripheral hearing by increasing the time synchronisation between neural structures.[14] The chirp stimulus provides stimulus to all the regions of the cochlea at approximately the same time. It is an acoustic stimulus whose frequency changes (increasing or decreasing) over time. This time synchronisation can provide a stimulus with a delay at higher frequencies compared to lower frequencies. However, the direct effect of this stimulus on the vestibular pathway is not yet clear. [15] In literature, several chirp stimuli have been defined such as the Claus Elberling (CE) chirp, wide band chirp, Narrow band (NB) chirp, and CW-VEMP chirp.

In this study, there were 2 patients in the patient group who did not respond with 500 Hz TB in the oVEMP test, but responded with 500 Hz NB LS CE-Chirp stimulus. oVEMP occurs from small amplitude waves because the eye muscles responding are extremely small. That the amplitude with the chirp stimulus was significantly larger compared to the TB stimulus is extremely important in respect of increasing the detectability of the wave.

Studies in literature vary related to the effect on the vestibular system in addition to the hearing system in blast trauma.

There are studies in literature that have reported that vertigo in blast trauma is due to secondary or third-degree mechanisms causing vibration in the central nervous system rather than inner ear damage. Peripheral vestibular etiologies following trauma include BPPV,

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perilymphatic fistula, and acute trauma to the utricle and saccule of the inner ear.[16] In a 2007 study of 258 patients exposed to blast trauma, dizziness was reported in 15% of the patients.[1] In another study, dizziness was seen in 18% of patients exposed to blast trauma who had no history of dizziness or imbalance. It has been reported that this symptom emerges in the later term. DHI of moderate-severe level was observed 17% of patients in the 6th month, but no significant difference was determined in the severity of dizziness evaluated with the DHI immediately after the trauma and in the 6th month. [17]

In a study by McCabe et al., guinea pigs were exposed to intense noise in the range of 136-150 dB SPL, and the harmful effects were seen to be limited to the pars inferior (cochlea and saccule),whereas the pars superior (utricle and semi-circular canals) was relatively intact. [6] Another study in 2017 reported vertigo in 8 of 41 patients exposed to blast trauma. In 4 of these 8 patients, nystagmus was also determined and in 7 of the 8, TM perforation. With the exception of one patient with stapes footplate fracture who initially presented with irritative peripheral vestibular syndrome, the vertigo in all the other patients disappeared within 3 months. [10]

Scherer et al., compared dizziness in 24 American soldiers with blast-associated traumatic brain injury within the last year in two groups of symptomatic and asymptomatic. When the symptomatic patients with dizziness were examined with videonystagmography, unilateral vestibular hypofunction was seen more, and unexplained nystagmus associated with central vestibular dysfunction was reported in both groups. The authors stated that these vertigo cases are usually related to head trauma associated with secondary or third-degree blast injuries. In the same study, the cVEMP test was applied to 14 patients and there was seen to be no response on one side in 2 patients. Two of the 14 patients also showed abnormally prolonged P1 latency, suggesting potential saccular or medial vestibulospinal system dysfunction. In 2 of 18 patients in the Subjective Visual Vertical test, abnormal deviation to the right was observed, which suggested possible unilateral otolith involvement. In the DHIs applied, the symptomatic

group scores were found to be significantly different from those of the asymptomatic group. However, no information was provided about the hearing status of the patients. [18]

In a 2018 study of patients exposed to fireworks explosions, dizziness was seen in 33%. In the evaluation of the vestibular system of these patients, canal paresis was determined in the caloric test in 3 of 40 affected ears, and in the cVEMP and oVEMP tests, which could only be applied in 10 affected ears, cVEMP absence was determined in 8 ears, normal cVEMP in 2 ears, reduced amplitude oVEMP in 2 ears, and no response to oVEMP in 4 ears. Hearing loss, cVEMP abnormality, and oVEMP abnormality were seen at significantly higher rates than abnormality in the caloric test. From these results it was concluded that the cochlea, utricle and saccule were affected by blast trauma but the semi-circular canals were protected from the blast effect. [19]

Although vestibular damage is probably related to the close anatomic proximity of the utricle and saccule to the stapes footplate, it has been rarely reported, and these studies have associated the injury to saccular and utricular damage or direct head trauma. Utricle and saccule ruptures have been identified in the postmortem findings of individuals who have died in explosions. [20]

In a 2014 study of 110 patients with blast trauma and a control group of 54 subjects, greater hearing loss at 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, and 6000 Hz was observed in the blast trauma group than in the control group, and dizziness was observed significantly more in the blast trauma patients. When dizziness was evaluated independently, it was observed to be correlated with increasing hearing thresholds. [21]

In the current study, the mean DHI score of the patient group was found to be 14.80±23.38 (range, 0-88). Of the 43 affected ears in the patient group, no cVEMP response was obtained with 500 Hz TB stimulus in 3 (6.9%) and no oVEMP response was obtained with 500 Hz TB in 5 ears (11.6%). The DHI score was found to be high in 2 patients; 74 in one and

88 in the other. In the patient with a DHI score of 74, there was cVEMP response and no response was observed in oVEMP. In the patient with a DHI score of 88, a response was observed to both cVEMP and oVEMP. These results could show that in some patients a part of the vestibular pathway is affect by blast trauma. When the differences between the patient group and control group are examined, no statistically significant difference was observed between the two groups in respect of cVEMP P1 latency, N1 latency, and P1N1 amplitude applied with 500 Hz TB and 500 Hz NB LS CE-chirp stimuli, and in oVEMP P1 latency, N1 latency, and P1N1 amplitude. These findings of the current study that the TM was intact in the patient group suggest that the vestibular system was protected from the blast effect. However, these tests were conducted at mean 41.16 days after the blast trauma, so the findings could indicate that blast trauma creates no significant change in the vestibular system in the chronic period. The different results of the effect of blast trauma on the vestibular system in this study and in other studies in literature could be due to several reasons. The severity and duration of the blast exposed to, and the position of the individual at the moment of the explosion could affect these differences in the findings. Moreover, different vestibular tests used in different studies could be extremely important in the results. Most studies in literature have used a limited test battery in the evaluation of the vestibular system after blast trauma. This makes it impossible to evaluate all the vestibular pathways together. In the current study, the utricle, saccule, superior and inferior vestibular nerves, and related pathways were evaluated.

In the comparisons of the VEMP responses of the patient and control groups, statistically similar results were obtained with both the TB stimulus and the chirp stimulus. From this result, it can be said that just as the chirp stimulus can be used in healthy individuals, it can also be used instead of the TB stimulus in patient groups.

The most important limitation of this study was the low number of subjects. However, the changes seen in the ear as a result of blast trauma are extremely heterogenous. These not

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only causes sensorineural hearing loss, but also TM perforation at a high rate, and ossicle chain ruptures. Therefore, this study only included patients with sensorineural hearing loss which was thought to have affected the cochlea, following blast trauma, and in addition to the cochlea and auditory system it was aimed to determine to what extent the vestibular system was affected with the use of cVEMP and oVEMP. Another limitation of the study was that not all the patients had been evaluated in respect of the audiovestibular system immediately after the blast. The patients presented at the Ear, Nose, and Throat Clinic at an average of 41.16±16.75 days after the blast, and audiological and vestibular tests were then applied. Therefore, patients who presented in the first days after the blast or after 90 days were excluded from the study. This suggests that at the time of presentation, the patients were in the late term of the blast trauma. Multi-organ injuries as a result of an explosion are seen extremely frequently, and as these injuries are often orthopaedic, these patients can only consult our polyclinic after their condition has stabilised.

- Blast trauma affecting the cochlea may also affect the vestibular system due to the close anatomical proximity.
- In cVEMP and oVEMP tests there was no significant difference in comparison of P1 latency, N1 latency and P1N1 amplitude between control and patient groups for both TB stimulus and NB LS CE-chirp stimulus.
- The functions of otolith organs were not affected in the late period after blast trauma.

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CONCLUSION

In conclusion, vestibular function of young adults, as measured by cVEMPS, oVEMPs and DHI is not affected by blast injuries in the long term. An extremely detailed examination of the vestibular system should be made following blast trauma, and if possible, a broad vestibular system evaluation test battery should be used which will be able to evaluate all parts of the vestibular system.

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References

1 Cave KM, Cornish EM, Chandler DW. Blast injury of the ear: clinical update from the global war on terror. *Mil Med* 2007;**172**:726-30

2 Garth RJ. Blast injury of the auditory system: a review of the mechanisms and pathology. *J Laryngol Otol* 1994;**108**:925-9

3 Choi CH. Mechanisms and treatment of blast induced hearing loss. *Korean J Audiol* 2012;**16**:103-7

4 Patterson JH Jr, Hamernik RP. Blast overpressure induced structural and functional changes in the auditory system. *Toxicology* 1997; **121**:29-40

5 Fife TD, Colebatch JG, Kerber KA, Brantberg K, Strupp M, Lee H et al. Practice guideline: Cervical and ocular vestibular evoked myogenic potential testing: Report of the Guideline Development, Dissemination, and Implementation Subcommittee of the American Academy of Neurology. *Neurology* 2017;**89**:2288-2296

6 McCabe BF, Lawrence M. The effects of intense sound on the non-auditory labyrinth. *Acta Otolaryngol* 1958 ;**49**:147-57

7 Mangabeira- Albernaz PL, Covell WP, Eldredge DH. Changes in the vestilbular labyrinth with intense sound. *Laryngoscope* 1959;**69**:1478-93

8 Jacobson GP, Newman CW. The development of the Dizziness Handicap Inventory. *Arch Otolaryngol Head Neck Surg* 1990;**116**:424-7

9 Canbal M, Cebeci S, Duyan GÇ, Kurtaran H, Arslan İ. Baş Dönmesi Engellilik Envanterinin Türkçe Geçerlilik ve Güvenilirlik Çalışması. *TJFM&PC* 2016;**10**:19-24

10 Ballivet de Régloix S, Crambert A, Maurin O, Lisan Q, Marty S, Pons Y. Blast injury of the ear by massive explosion: a review of 41 cases. *J R Army Med Corps* 2017;**163**:333-338

11 Lee JS, Lee SK, Shin IH, Yeo SG, Park MS, Byun JY. Vestibular evoked myogenic potential according to middle ear condition in chronic otitis media with tympanic membrane perforation. *Acta Otolaryngol* 2014;**134**:34-40

12 Felipe L, Kingma H. Ocular vestibular evoked myogenic potentials. *Int Arch Otorhinolaryngol* 2014; **18**:77-9

13 Erbek S, Gokmen Z, Ozkiraz S, Erbek SS, Tarcan A, Ozluoglu LN. Vestibular evoked myogenic potentials in preterm infants. *Audiol Neurootol* 2009;**14**:1-6

14 Elberling C, Callø J, Don M. Evaluating auditory brainstem responses to different chirp stimuli at three levels of stimulation. *J Acoust Soc Am* 2010;**128**:215-23

15 Atcherson SR, Moore PC. Are chirps better than clicks and tonebursts for evoking middle latency responses? *J Am Acad Audiol* 2014;**25**:576-83

16 Darley DS, Kellman RM. Otologic considerations of blast injury. *Disaster Med Public Health Prep* 2010;**4**:145-52

17 Remenschneider AK, Lookabaugh S, Aliphas A, Brodsky JR, Devaiah AK, Dagher W et al. Otologic outcomes after blast injury: the Boston Marathon experience. *Otol Neurotol* 2014;**35**:1825-34

18 Scherer MR, Burrows H, Pinto R, Littlefield P, French LM, Tarbett AK et al. Evidence of central and peripheral vestibular pathology in blast-related traumatic brain injury. *Otol Neurotol* 2011;**32**:571-80

19 Liao YH, Young YH. Inner Ear Damage by Firecracker Trauma. *Audiol Neurootol* 2018;**23**:116-121

20 Cohen JT, Ziv G, Bloom J, Zikk D, Rapoport Y, Himmelfarb MZ. Blast injury of the ear in a confined space explosion: auditory and vestibular evaluation. *Isr Med Assoc J* 2002;**4**:559-62

21 Shah A, Ayala M, Capra G, Fox D, Hoffer M. Otologic assessment of blast and nonblast injury in returning Middle East-deployed service members. *Laryngoscope* 2014;**124**:272-7

Table 1. Hearing thresholds of the affected ears in the patient group

n=43	Mean+SD	Median (min-max)
PTA	27.60±13.88	23.00 (7.00-63.00)
250 Hz	20.46±12.33	20.00 (10.00-70.00)
500 Hz	19.41±13.68	15.00(5.00-70.00)
1000 Hz	16.86±14.35	15.00(0-70.00)
2000 Hz	28.02±21.49	20.00(0-80.00)
4000 Hz	44.53±21.37	40.00(10.00-90.00)
6000 Hz	51.86±26.41	50.00(10.00-120.00)
8000 Hz	51.27±25.86	50.00(0-110.00)

PTA:Pure tone audiometry (500-1000-2000-4000 Hz),
SD:Standart deviation, min:minimum, max:maximum

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Table 2. The comparisons of the pure tone averages, and hearing thresholds at low frequencies (250-500 Hz), mid frequencies (1000-2000 Hz) and high frequencies (4000- 6000- 8000 Hz) of the affected and non-affected ears in the patient group

	Affected ear (n=43)		**Non-affected ear (n=7)**		
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	p
PTA	27.60±13.88	23.00 (7.00-63.00)	6.00 ± 1.82	5.00 (5.00-10.00)	**0.000***
Low frequency threshold	19.94 ± 12.43	17.50 (7.50-70.00)	15.71 ± 3.13	15.00 (12.50-20.00)	0.713*
Mid frequency threshold	22.44 ± 15.79	15.00 (2.50-60.00)	6.78 ± 2.37	5.00 (5.00-10.00)	**0.001***
High frequency threshold	49.19 ± 22.60	45.00 (16.60-103.30)	7.95 ± 4.46	7.50 (3.30-15.00)	**0.000***

*: Mann Whitney U test
PTA: PTA:Pure tone audiometry (500-1000-2000-4000 Hz)
SD:Standart deviation, min:minimum, max:maximum.

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Table 3. Comparison of 500 Hz TB cVEMP P1 latency, N1 latency and P1N1 amplitude between patient and control groups. $p<0.05$ was considered significant.

	Control group(n=44)		Patient group (n=40)		
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	p
P1 latency (ms)	15.13±1.81	14.33 (13.00-20.00)	15.33±2.09	15.00 (12.00-22.33)	0.467*
N1 latency (ms)	24.77±2.62	24.67 (19.67-35.00)	24.62±2.19	24.50 (20.33-32.00)	0.925*
P1N1 amplitude (μV)	75.11±35.23	74.40(15.24-153.70)	94.78±45.39	88.98 (20.29-225.00)	0.066*

*: Mann-Whitney U test
(ms:millisecond, μV:mikrovolt, SD:Standart deviation, min:minimum, max:maximum)

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Table 4. The comparision of cVEMP responses with 500 Hz LS CE-Chirp stimulus of the patient and control groups.

$p<0.05$ was considered statistically significant

	Control group(n=44)		Patient group (n=40)		
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	p
P1 latency (ms)	11.48±1.68	11.33 (8.00-17.00)	11.60±2.04	11.33 (6.67-18.00)	0.576*
N1 latency (ms)	20.93±2.72	20.16 (16.00-30.67)	20.77±2.61	20.67 (15.33-26.00)	0.993*
P1N1 amplitude (µV)	86.76±36.22	89.62(16.17-169.30)	105.58±47.99	99.99 (31.62-277.10)	0.078*

*: Mann-Whitney U test
(ms:milisecond, µV:microvolt, SD:Standart deviation, min-max:minimum-maximum)

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Table 5. The comparision of oVEMP responses with 500 Hz TB stimulus of the patient and control groups.

$p<0.05$ was considered statistically significant

	Control group(n=44)		Patient group (n=38)		
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	p
P1 latency (ms)	16.06±1.65	16.16 (13.00-20.33)	16.12±1.73	16.50 (11.00-18.67)	0.484*
N1 latency (ms)	11.43±1.32	12.00 (8.00-14.00)	11.41±1.27	11.67 (8.67-14.67)	0.933*
P1N1 amplitude (μV)	6.85±5.59	5.09(0.99-26.17)	7.27±4.95	5.36 (2.09-25.80)	0.289*

*: Mann-Whitney U test
(ms:milisecond μV:mikrovolt, SD:Standart deviation, min-max:minimum-maximum)

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Table 6. The comparision of oVEMP responses with 500 Hz LS CE-Chirp stimulus of the patient and control groups.

$p<0.05$ was considered statistically significant

	Control group(n=44)		Patient group (n=40)		
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	p
P1 latency (ms)	12.09±1.56	12.50 (9.33-14.67)	12.85±1.83	12.83 (8.33-16.67)	0.081*
N1 latency (ms)	7.40±1.43	7.33 (3.67-10.33)	8.05±1.67	7.67 (3.67-14.00)	0.062*
P1N1 amplitude (µV)	11.27±9.43	8.08(1.31-46.78)	11.77±8.02	10.07 (2.74-38.57)	0.418*

*: Mann-Whitney U test
(ms:milisecond, µV:microvolt, SD:Standart deviation, min-max:minimum-maximum)

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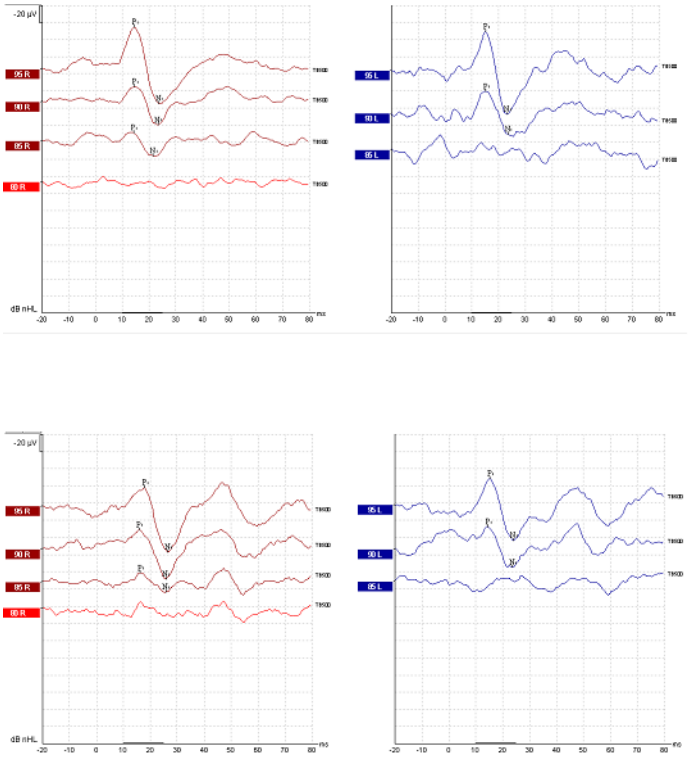

Figure 1. cVEMP sample of the patient (top) and control (bottom) groups with 500 Hz TB stimulus

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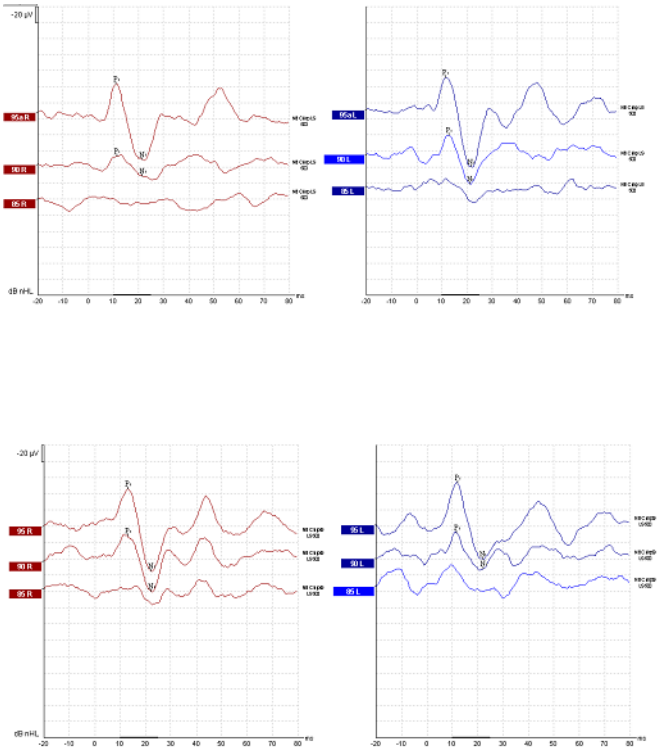

Figure 2. cVEMP sample of the patient (top) and control (bottom) groups with 500 Hz LS CE-Chirp stimulus

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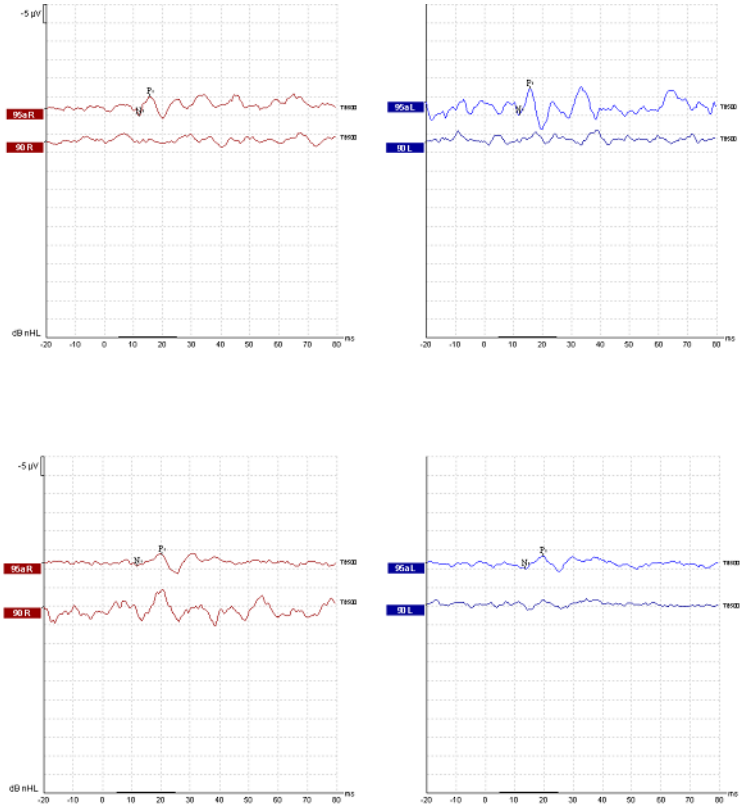

Figure 3. oVEMP sample of the patient (top) and control (bottom) groups with 500 Hz TB stimulus

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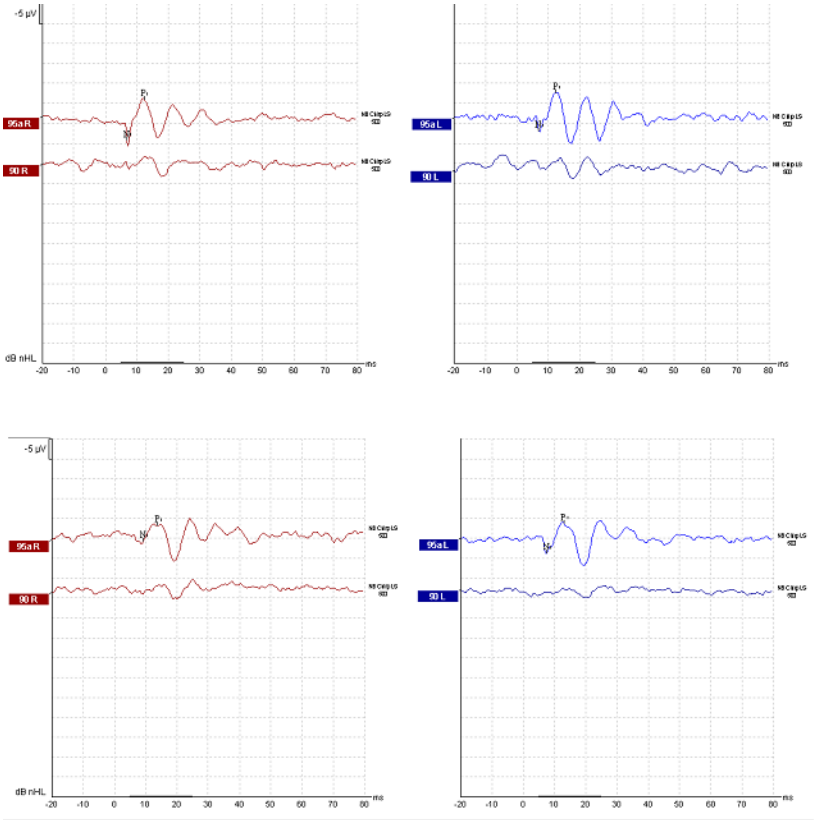

Figure 4. oVEMP sample of the patient (top) and control (bottom) groups with 500 Hz LS CE-Chirp stimulus

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