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Original Article

Evaluation of Vestibulo-Ocular Reflex (VOR) in Tinnitus Patients with Normal Hearing

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OBJECTIVES: This study aimed to evaluate the correlation between tinnitus parameters (duration, severity, reaction, handicap levels) and vestibulo-ocular reflex (VOR) gain values in patients with tinnitus with normal hearing without vertigo or any other complaints and to compare the VOR gains with a healthy group.

MATERIALS and METHODS: The study group consisted of 30 individuals aged between 18 and 65 years who suffered from tinnitus but not from hearing loss and vertigo. The control group also consisted of 30 individuals who were categorized as healthy adults. The tinnitus handicap inventory, tinnitus reaction questionnaire, and tinnitus handicap questionnaire were applied to each individual in the tinnitus group, and the video head impulse test (VHIT) was conducted in 2 groups.

RESULTS: Statistically, a significant difference was found between the 2 groups in terms of VOR gain values in horizontal and vertical semicircular canal planes ($p<0.05$). However, there was no statistically significant correlation between tinnitus parameters, age, and VOR gain values in the study group ($p>0.05$).

CONCLUSION: Considering the lower VOR gain values of the study group than the control group, these patients may need to be followed up for vestibular dysfunction associated with tinnitus, which can be a symptom of peripheral vestibular disorder. Moreover, this study will contribute to the literature because we determined a high-frequency component of VOR by VHIT, which was used to evaluate the relationship between tinnitus parameters and peripheral vestibular function.

KEYWORDS: Tinnitus, Video Head Impulse Test, Tinnitus Handicap Inventory, Tinnitus Reaction Questionnaire, Tinnitus Handicap Questionnaire

INTRODUCTION

Tinnitus affects approximately 10%-15% of the adult world population and is characterized by the detection of 1 or more sounds in the ears/head in the absence of an external acoustic signal [1]. Tinnitus is correlated with hearing loss: according to the literature [2], 8%–10% of patients presented with normal audiometry test results. However, neuro-otological findings are limited for patients with tinnitus with normal hearing [2, 3], leaving the link between tinnitus and the vestibular system unresolved. Ila et al. [3] found a relationship between tinnitus with normal hearing and abnormal caloric response, and it was hypothesized that a vestibular system disorder could be affected by tinnitus, even without hearing loss. Therefore, it has been suggested that a vestibular evaluation should also be conducted in patients with tinnitus [3].

A videonystagmography (VNG), a caloric test, a vestibular evoked myogenic potentials test, and a video head impulse test (VHIT), can each examine this relationship. The latter is a new semicircular canal (SCC) function test based on the head impulse test defined by Halmagyi and Curthoys, which utilizes a high-speed digital video camera to record head and eye movements during and immediately after passive head rotations. This clinical tool quantitatively evaluates the function and high-frequency component of the vestibulo-ocular reflex (VOR) of SCCs [4–7].

The low frequency component of the VOR is measured by the caloric test and has been used to evaluate the relationship between the tinnitus level and the peripheral vestibular function [2,3]. In this study, we investigated the relationship between the tinnitus parameters (that is, severity, duration, psychological distress level, and handicap level) and the VOR gain values by VHIT in patients with tinnitus with normal hearing and no vertigo complaints. We then compared the VHIT results with those of a (healthy) control group.

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The hypothesis we propose is that there is vestibular involvement in patients with tinnitus even though they have a normal hearing range and are without vertigo or other balance problems.

Specifically, this study poses the following questions:
(1) Can vestibular involvement be detected by a high-frequency VOR test in these patients?
(2) Are the levels of tinnitus severity, duration, psychological stress, and handicap level directly correlated with the vestibular involvement level?
(3) Are the tinnitus ear side and the affected SCC side positively correlated?

Given that there is a dearth of studies on this topic and that the high-frequency evaluation of VOR has not been used in evaluating the relationship between tinnitus severity and the peripheral vestibular function, our study contributes to the literature.

MATERIALS AND METHODS

Subjects
This prospective and cross-sectional study was conducted in an Ear Nose Throat (ENT) department. The study was approved by the local ethics committee and was conducted according to the ethical standards of the Helsinki Declaration. Informed consent (written and verbal) was obtained from all participants.

The study group consisted of 30 patients referred to the ENT department for tinnitus only; the control group consisted of 30 age-matched, healthy participants. The participants in both groups were selected randomly.

Participants were selected on the basis of the following criteria: having tinnitus for at least 3 months; aged between 18 and 65 years; having normal otological and hearing results (pure-tone average [PTA] ≤25 decibels in hearing level [dB HL]) according to Goodman's classification [8]; and having no vertigo complaints throughout life. Participants with otological problems such as chronic otitis media, tympanic membrane perforation, and outer ear atresia; metabolic disease; neurological, psychological, and mental illness; temporomandibular joint dysfunctions; vertigo; and PTA ≥26 dB HL were excluded.

Procedure
The study group completed tinnitus reaction questionnaire (TRQ), tinnitus handicap inventory (THI), and tinnitus handicap questionnaire (THQ); pure-tone audiometry test and VHIT were conducted in both groups.

The tinnitus reaction questionnaire (TRQ), comprising 26 questions, measures psychological distress related to tinnitus. The responses are summed, resulting in a range between 0 and 104, with higher scores denoting higher levels of tinnitus-related distress. There is no recommended grading system for TRQ scores [9].

The tinnitus handicap inventory (THI), including 25 questions, is a validated questionnaire for quantifying tinnitus severity and for assessing the impact of tinnitus on daily life. It results in a score ranging from 0 to 100. A higher score indicates a higher tinnitus-related handicap and a higher tinnitus severity [10]. We categorized tinnitus severity scores according to Aksoy et al. [11]: slight (0–16), mild (18–36), moderate (38–56), severe (58–76), and catastrophic (78–100).

The tinnitus handicap questionnaire (THQ) consists of 27 questions, with each question scored between 0 and 100 points, with the maximum score being 2,400 points. A higher THQ score indicates a higher handicap on hearing, social relations, general health, and the individual's emotional state with tinnitus [12]. There is also no recommended grading system for THQ scores.

It took the study group a total of 30 minutes to answer all the questionnaires.

The pure-tone audiometry test was conducted by an audiologist using the Clinical Audiometer device (Interacoustics AC40, Middelfart, Denmark) in a quiet and isolated cabin in accordance with the standards. Pure-tone air conduction thresholds were obtained using a modified Hughson–Westlake procedure for test frequencies of 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz [13]. The air conduction thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz were summed and divided by 4 to define PTA. Pure-tone average (PTA) ≤25 dB HL at these 4 frequencies was deemed normal hearing according to Goodman's classification [8] for both groups. The participants completed this test in 20 minutes.

For the study group, the audiogram shapes were classified into 3 configurations: high-frequency sloping (HFS), flat, and low frequency rising (LFR). According to the modified criteria established by Demeester et al. [14], the HFS was defined as the difference between the mean of the hearing thresholds at 500/1000 Hz and mean of the hearing thresholds at 4000/8000 Hz above 15 dB. Flat audiograms had differences among means at 250/500 Hz, 1000/2000 Hz, and 4000/8000 Hz ≤15 dB. An low frequency rising (LFR) audiogram was defined when the difference between the poorer low frequency and the best threshold in higher frequencies was >15 dB.

Finally, the VHIT was performed with the ICS Impulse Device (GN Otometrics, Taastrup, Denmark), with the test preparation procedure similar to Limviriyakul et al. [15]. We tested each pair of SCCs: the right/left lateral canals, the right/left anterior and posterior (RALP) canals, and the right/left anterior and posterior (LARP) canals. A result was accepted when the peak head velocities ranged between 150 and 250° per second with a 10°–20° amplitude. For each pair of SCCs, a

MAIN POINTS

- The video head impulse test is clinically important for vestibular evaluation.
- A tinnitus complaint without hearing loss could be symptomatic of peripheral vestibular disorder because the high-frequency component of the vestibulo-ocular reflex was impaired in the study group.
- Peripheral vestibular disorders should be considered in patients with only tinnitus complaints, and evaluations for vestibular disorder should be conducted regularly.

minimum of 20 head impulses was accepted. The video head impulse test (VHIT) gain was calculated by the ICS Impulse Device as the ratio of the area under the curves of the eye-to-head movement. When the VOR gain dropped below 0.8 for the lateral and below 0.7 for the vertical SCCs, we defined the VHIT results as abnormal. The gain asymmetry ratio percentage was the difference between the right and left side gains, calculated by the formula: (R–L)/(R+L)×100 (where R, L = right, left absolute mean gain values) [16]. The VHIT preparation and application procedure took 15–20 minutes for the participants.

Statistical Analysis

All data were analyzed by the Statistical Package for Social Sciences (SPSS) 22 program (IBM Corp.; Armonk, NY, USA). An independent sample t-test compared the 2 independent groups, and one-way analysis of variance was used to compare 2 or more unrelated groups. The relationship between the variables was examined by Pearson's correlation coefficient. In interpreting the obtained values, the 0.05 significance level was used as the criterion.

RESULTS

The 30 study group participants consisted of 14 women and 16 men with the mean age being 41.96±12.27 (23–62). The 30 control group participants were equally divided by sex, with the mean age being 36.50±11.20 (20–58). The PTA means for right and left ears of the study group were 15.76±6.15 HL (4–24) and 16.20±5.84 HL (6–25), respectively; and of the control group were 13.93±6.16 HL (1–24) and 13.80±6.02 HL (3–24), respectively.

Table 1 displays the tinnitus side, duration, and severity as well as the THI, TRQ, and THQ scores of the study group. We found no significant difference in the THI, TRQ, and THQ scores according to sex and tinnitus side.

Table 2 displays the minimum, maximum, and average VOR gains for all SCCs in both groups. According to the VHIT results of the study group, a lower VOR gain (<0.8) was obtained in 13 patients for the left lateral SCC and 4 patients for the right lateral SCC. A total of 2 patients had a lower VOR gain (<0.7) for the left anterior SCC. The remaining 11 study group patients and all the control group participants had normal VOR gain values for all SCCs. A total of 9 study group participants had tinnitus ipsilateral to the SCC side with lower VOR gain; in the remaining patients, tinnitus was contralateral or bilateral.

On the basis of the results presented in Table 3, the VOR gain values in the right lateral, left lateral, left anterior, right posterior, left posterior, and right anterior SCCs all showed a statistically significant difference between the study and control groups (p<0.05). All VOR gain values were lower in the former than in the latter.

We found 2 patients with a symmetrical LFR, 13 with a symmetrical HFS, and 15 with a symmetrical flat audiogram. Lower VOR gain values were obtained in all patients with LFR, in 10 of 13 patients with HFS, and in 7 of 15 with a flat audiogram (Figure 1). Because only 2 cases had a rising audiogram, they were excluded; thus, the analysis was conducted with 28 participants. According to Table 4, the THI, THQ, and TRQ scores and VOR gain values did not show any significant difference for the audiogram shape (p>0.05).

Table 1. Tinnitus side, duration, handicap, related psychological distress, and severity of the study group

Parameters	N	%
Tinnitus severity		
Slight	4.00	13.00
Mild	12.00	40.00
Moderate	3.00	10.00
Severe	3.00	10.00
Catastrophic	8.00	27.00
THI score, mean+SD (min–max)	51.73±26.87	(10–94)
Tinnitus side		
Bilateral	14.00	46.67
Right	9.00	30.00
Left	7.00	23.33
Psychological distress score (TRQ), mean+SD (min–max)	47.03±27.27	(4–93)
Tinnitus handicap score (THQ), mean+SD (min–max)	1,152.83±606.44	(200–2,310)
Tinnitus duration (month), mean+SD (min–max)	38.9±60.3	(3–240)
<6 months	10.00	33.00
>6 months	20.00	67.00

Min: minimum; Max: maximum; SD: standard deviation; THI: tinnitus handicap inventory; THQ: tinnitus handicap questionnaire; TRQ: tinnitus reaction questionnaire

Table 2. Minimum, maximum, and average VOR gains for all SCCs in both groups

	Group	$\bar{X}$±Ss	Min	Max
Right lateral SCC VOR gains	Study	0.910±0.134	0.66	1.3
	Control	1.017±0.089	0.83	1.28
Left lateral SCC VOR gains	Study	0.831±0.150	0.62	1.24
	Control	1.004±0.107	0.8	1.28
Right anterior SCC VOR gains	Study	1.168±0.158	0.82	1.48
	Control	1.295±0.120	0.95	1.5
Left anterior SCC VOR gains	Study	1.005±0.171	0.58	1.29
	Control	1.098±0.138	0.84	1.45
Right posterior SCC VOR gains	Study	0.983±0.161	0.74	1.29
	Control	1.076±0.162	0.8	1.39
Left posterior SCC VOR gains	Study	1.152±0.088	0.9	1.31
	Control	1.226±0.087	1.02	1.36

SCC: semicircular canal; VOR: vestibulo-ocular reflex.

We found no statistically significant correlation between tinnitus duration, severity, age, THI score, THQ score, TRQ score, and VOR gain values in all SCCs (p>0.05). Positive and moderate correlation was found between the tinnitus duration and the THQ score. From the THQ score, we derived a 20% of variance in tinnitus (p<0.05; r=0.45;

Table 3. Comparison of VOR gains in all SCCs between study and control groups

Variable	Group	N	$\bar{X}$±Ss	t-test	p
RL	Study	30	0.910±0.134	-3.62	0.01
	Control	30	1.017±0.089		
LL	Study	30	0.831±0.150	-5.13	0.01
	Control	30	1.004±0.107		
LA	Study	30	1.005±0.171	-2.33	0.02
	Control	30	1.098±0.138		
RP	Study	30	0.983±0.161	-2.23	0.03
	Control	30	1.076±0.162		
LP	Study	30	1.152±0.088	-3.29	0.01
	Control	30	1.226±0.087		
RA	Study	30	1.168±0.158	-3.51	0.01
	Control	30	1.295±0.120		

RL: right lateral; LL: left lateral; LA: left anterior; RP: right posterior; LP: left posterior; RA: right anterior; SCC: semicircular canal; VOR: vestibulo-ocular reflex

Table 4. Comparison of THI, THQ, TRQ, and VOR gain results by audiogram shape

Variable	Group	N	X±Ss	t-test	p
RL	Flat	15.00	0.959±0.143	1.93	0.06
	Sloping	13.00	0.863±0.116		
LL	Flat	15.00	0.882±0.162	1.69	0.10
	Sloping	13.00	0.786±0.130		
LA	Flat	15.00	0.963±0.161	-1.92	0.07
	Sloping	13.00	1.076±0.147		
RP	Flat	15.00	0.955±0.166	-0.99	0.33
	Sloping	13.00	1.016±0.161		
LP	Flat	15.00	1.170±0.072	1.17	0.25
	Sloping	13.00	1.130±0.107		
RA	Flat	15.00	1.168±0.171	0.03	0.98
	Sloping	13.00	1.166±0.160		
THI	Flat	15.00	57.06±27.88	0.87	0.39
	Sloping	13.00	48.15±26.10		
THQ	Flat	15.00	1,085.±595.3	-0.65	0.56
	Sloping	13.00	1,240.±660.3		
TRQ	Flat	15.00	47.07±24.90	-0.27	0.79
	Sloping	13.00	49.93±30.45		

RL: right lateral; LL: left lateral; LA: left anterior; RP: right posterior; LP: left posterior; RA: right anterior; THI: tinnitus handicap inventory; THQ: tinnitus handicap questionnaire; TRQ: tinnitus reaction questionnaire

r^2=0.20). We also found a positive and high correlation between the TRQ and THQ scores and between the THI score and the tinnitus severity (r=0.86; r=0.83, respectively; p<0.05) (Table 5).

Table 5. The correlation between tinnitus duration, severity, age, THI scores, THQ scores, TRQ scores, and VOR gain values

	THI Score		Severity		THQ Score		TRQ Score	
	R	P	R	P	R	P	R	P
RL	0.17	0.37	0.01	0.98	0.07	0.73	0.09	0.63
LL	0.14	0.45	0.02	0.91	0.07	0.72	0.21	0.26
LA	0.18	0.34	0.21	0.27	0.29	0.12	0.36	0.06
RP	0.28	0.14	0.21	0.26	0.32	0.08	0.33	0.08
LP	-0.02	0.90	-0.05	0.81	-0.14	0.45	0.03	0.88
RA	-0.03	0.88	-0.10	0.61	-0.18	0.34	-0.08	0.67
Tinnitus duration	0.34	0.07	0.33	0.07	0.45	0.01	0.29	0.12
Age	0.02	0.92	0.04	0.85	0.05	0.78	0.01	0.99
TRQ	0.78	0.01	0.73	0.01	0.82	0.01		
THQ	0.86	0.01	0.83	0.01				

R: correlation coefficient; P: P value- probability value; RL: right lateral; LL: left lateral; LA: left anterior; RP: right posterior; LP: left posterior; RA: right anterior; THI: tinnitus handicap inventory; THQ: tinnitus handicap questionnaire; TRQ: tinnitus reaction questionnaire; VOR: vestibulo-ocular reflex.

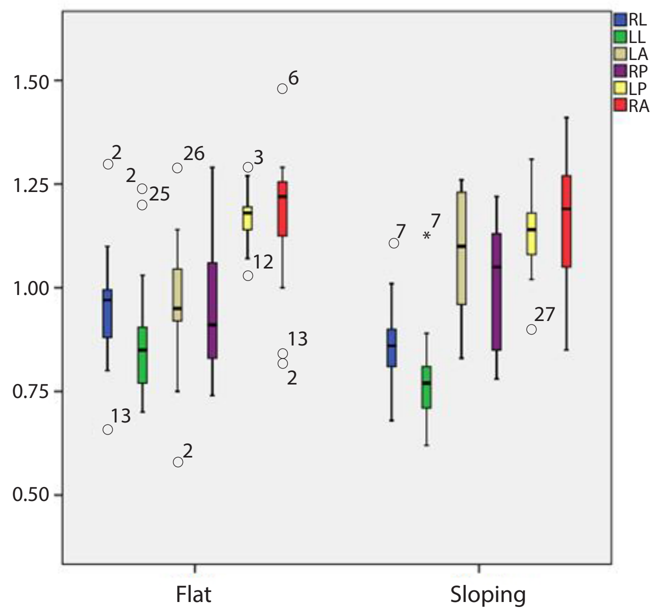

Figure 1. Box-plot graphic of vestibulo-ocular reflex gains in all the semicircular canals versus audiogram shapes.

There was no statistically significant difference between the tinnitus duration <6 months and >6 months as regards VOR gains in all the SCCs (p>0.05).

DISCUSSION

Our study investigated the relationship between the tinnitus parameters (that is, severity, duration, psychological distress level, and handicap level) and the VOR gain values in all SCCs in patients with tinnitus with normal hearing and no vertigo complaints. We then compared the VHIT results with the control group.

A positive correlation between tinnitus duration, depression, anxiety, and stress level was found in the literature [17]. However, in our study, there was no correlation between the tinnitus duration and the TRQ scores. We thought that evaluating the relationship between tinnitus duration and psychological effects of patients using detailed scales such as depression and anxiety inventories, may bolster our study's conclusions. Conversely, we found a relationship between tinnitus severity and psychological distress, which comports with the literature [17]. The literature also found a significant relationship between severe tinnitus and the discomfort level related to tinnitus and anxiety and depression [18,19].

A study evaluating the relationship between tinnitus parameters (duration and severity) and vestibular symptoms found no difference in vestibular abnormalities between patients with acute and chronic tinnitus for the tinnitus duration [3]. However, more abnormal caloric responses were found in patients with severe tinnitus than in patients having mild to moderate tinnitus. Our study is the first to evaluate the correlation between high-frequency responses of the vestibular system and the tinnitus parameters. This relationship was evaluated in detail with different questionnaires. We found no difference between patients with tinnitus for at least 6 months and less than 6 months for the VOR gains in all the SCCs. Moreover, unlike Ila et al. [3], we found no significant relationship between the tinnitus parameters and the VHIT.

Although tinnitus characteristics have been defined in individuals with normal hearing, the literature on neuro-autological findings for these individuals is limited. One study found that unilateral canal paresis was obtained in 15 of 17 patients with normal hearing and no vestibular complaints in the caloric test. Of these 15 patients, unilateral tinnitus was observed in 13, and bilateral tinnitus was reported in the remaining 2. A total of 12 patients with unilateral canal paresis had tinnitus on the same side. Morales-Garcia et al. [2] also reported that for patients with unilateral tinnitus, the Romberg test was sensitive on the same side as the tinnitus. Ila et al. [3] also found abnormal caloric responses in 13 of 32 patients with tinnitus with normal hearing (40.6%) without vestibular complaints. On the contrary, they found no significant abnormal result in the VNG test; therefore, they thought that tinnitus might be a symptom of peripheral vestibular disease. When they compared the caloric test responses on the basis of tinnitus severity, they found that abnormal caloric responses were higher in patients with severe tinnitus than in those with mild and moderate tinnitus [3].

Our study found that VOR gains in all SCCs were significantly lower in the study group than in the control group. Because of obtaining a lower VOR gain than normal in 19 of 30 patients, we hypothesize that tinnitus might be symptomatic of a peripheral cochleo-vestibular disorder. In these 19 patients, the tinnitus side of only 9 was compatible with a lower VOR gain SCC side. This result does not evidence a strong correlation between the tinnitus side and the SCC side, with a low VOR gain. Considering patients with bilateral tinnitus and the unilateral side with a low VOR gain, the question of whether vestibular involvement begins before tinnitus needs to be further investigated.

In our study, 2 patients had LFR, 13 had HFS, and 15 had a flat audiogram. Lower VOR gain values were obtained in the 2 patients with LFR and in 10 of 13 patients with an HFS audiogram configuration. Age-related deterioration of the semicircular canals, the otolith organs, and age-related cochlear degeneration have been found in the literature [20–25]. Because a sloping audiogram can be symptomatic of age-related hearing loss, the presence of patients with audiogram configuration (sloping audiogram) seen in age-related hearing loss and lower VOR gain in at least 1 SCC can be considered a result of age-related deterioration of the peripheral vestibular and cochlear function.

Moreover, in our study, it can be argued that in patients with tinnitus with a LFR audiogram and a decrease in the VOR gain in at least 1 SCC may also result from delayed hydrops. In Meniere's disease, there may be situations where vertigo attacks and hearing loss are not observed at the same time. Sensorineural hearing loss can prevent vertigo attacks for months or years, known as delayed hydrops [26]. Tokumasu et al. [27] found that 17 of 28 patients (61%) had otological findings before the onset of vertigo attacks, which can be explained using the experimental hydrops method of obscuration of the enduralymphatic duct in Kimura's guinea pigs. They assumed that a very mild or non-vestibular asymmetry in the vestibular nuclei could not induce vertigo or spontaneous nystagmus but could only produce cochlear symptoms by the slow progressive formation of unilateral labyrinthine hydrops.

Given the above information, cochlear changes are assumed to affect posterior labyrinth structures, and many patients with tinnitus may show abnormal vestibular test results even in the absence of vertigo [28]. Therefore, owing to the anatomical and functional affinities of the vestibular and auditory systems, it is very important to comprehensively evaluate these 2 systems in patients with tinnitus.

The literature has found that patients with tinnitus with normal hearing are infrequent: an incidence of 8%–10% [29]. A study evaluating 744 patients with tinnitus found that only 7.4% had normal hearing [30]. In another study wherein 457 patients with tinnitus were evaluated over a 10-year period, only 17 had normal hearing [2]. Our sample comprised 30 patients with tinnitus with normal hearing average. Although our study might be more valuable if we find more patients with normal hearing, it is difficult to find patients with tinnitus with a normal hearing average.

One of the limitations of our study was not evaluating the very low and low frequency responses of the vestibular system. Therefore, vestibular involvement with low frequency gains in patients with tinnitus with normal hearing could not be determined. As the caloric test is a very low-frequency test (0.003 [0.002–0.004] Hz), rotatory chair test is a low-frequency test (0.01–2 Hz), and VHIT is a high-frequency (4–7 Hz) test [31, 32], we believe that a more comprehensive study evaluating the results of these 3 tests together in the group with tinnitus with normal hearing with no vestibular symptoms can offer further extensive results about SCCs involvement and can guide future studies.

CONCLUSION

Considering the lower VOR gain values of our study group patients vis-à-vis the control group, as well as the apparent manifestation of vestibular symptoms obtained in vestibular tests in patients with tinnitus with normal hearing in previous studies, patients with tinnitus with normal hearing may need a follow-up for vestibular evaluation because tinnitus can be a symptom of peripheral vestibular disorder.

Ethics Committee Approval: The study was approved by Ege University Medical Research Local Ethical Committe (approval date and number: 01/08/2019/99166796- 050.06.04) and was conducted according to the ethical standards of Helsinki Declaration.

Informed Consent: N/A.

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