Vestibular and cochlear dysfunction in aging: Two sides of the same coin?

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Abstract
Objective: Nonspecific complaints of hearing loss, vertigo, imbalance, and instability, without a defined etiology, are very prevalent in the elderly population, with a great impact on morbidity and mortality in this age group. The objectives of this study were to verify whether there is age-related vestibular dysfunction and to test the association of vestibular dysfunction with presbycusis in the elderly population.

Methods: Original retrospective analytical cross-sectional study, carried out with 80 patients who underwent a videonystagmography and complete audiometric evaluation due to nonspecific vestibular complaints, without a specific vestibular disorder diagnosis. Patients were selected and divided into two distinct age groups (group A: >60 years; group B: 18–50 years) and, in both groups, we analyzed the caloric tests and the pure-tone audiometry.

Results: In the vestibular evaluation, we found that there was a statistically significant difference ($P < 0.05$) between groups in the prevalence of bilateral vestibular weakness (group A: 22.5%; group B: 5%), and that the increase in age, above 60 years, is negatively correlated with the mean total caloric response. Additionally, we obtained a reasonable negative and statistically significant correlation ($r = -0.320$, $P < 0.05$) between the mean bone conduction thresholds at high frequencies and total caloric responses in group A.

Conclusions: In patients with hearing loss, it is essential to perform a complete vestibular study to diagnose vestibular disorders and, consequently, prevent adverse outcomes that may result from these alterations.

Keywords
aged, bilateral vestibulopathy, caloric tests, presbycusis, vertigo
INTRODUCTION

Many elderly people consult an otorhinolaryngologist for nonspecific complaints of hearing loss, vertigo, imbalance, and instability. Dizziness is even considered to be the most common complaint in patients older than 75 years.1,2 Additionally, it is estimated that the annual prevalence of patients over 60 years of age with complaints of vertigo or dizziness who require medical care or who have limitations in their daily activities is around 20%.1,3 So, as one of the causes for these complaints, age-related vestibular dysfunction may have a major impact on morbidity and mortality since one-third to a half of the geriatric population over 65 years of age has an annual fall-related injury.4

The vestibular system, constituted by its peripheral sensory portion and by a complex network of central neurons, is one of the main responsible for the sensation and precise perception of movements and balance. It is, at a basic level, composed of two major systems: a sensory one, which is responsible for the representation of self-motion and building an internal mapping of the body in space concerning gravity; and a second component, the motor system, capable of triggering effective postural and ocular motor reflexes to ensure static and dynamic balance, as well as to maintain visual acuity during head movements.5

Several pathologies can lead to vestibular dysfunction in the elderly, and sometimes the etiology is multifactorial.1,6,7 The most common causes for vestibular dysfunction that occurs with aging are bilateral peripheral vestibular hypofunction, central vertigo, and benign paroxysmal positional vertigo (BPPV).4,8 Additionally, to maintain balance, the vestibular system must interact effectively with other sensory inputs, including proprioceptive and visual.6 Thus, in this age group, age-related vision loss, polymedication, and sarcopenia itself can also contribute to the imbalance and unspecified dizziness observed in this age group. After a complete otoneurological examination, it is often not possible to determine a specific and unique etiology for the complaints presented.

Regarding the vestibular system, it is thought that the decline in the function of the semicircular canals is a significant component of the age-related vestibulopathy,9 and this decline can be documented through a videonystagmography (VNG). The VNG is a relatively simple test that allows the observation and recording of eye movements during testing maneuvers. It is fundamentally composed of three major tests: tests for assessing oculomotor function, positional tests, and caloric tests. Thus, it allows, in some cases, to determine whether a vestibular disease may be causing a balance or dizziness problem and also makes it possible to distinguish between a central or peripheral and uni- or bilateral vestibular disorder.10

Likewise, it is well established that, in aging, there is an age-related hearing loss, also known as presbycusis. Presbycusis is a gradual, sensorineural, bilateral and symmetrical hearing loss, caused by progressive degeneration of cochlear structures and central auditory pathways.11,12 This type of loss usually affects the highest frequencies first and then, gradually, progresses to medium and low frequencies.11 The prevalence of hearing loss in the elderly population varies from 30% to 90%, increasing the incidence and the degree of impairment at older ages.13

In light of this and knowing that the vestibular and auditory system, although distinct, share an embryological origin, vascularization, and neuroepithelium, the possibility of vestibular and cochlear dysfunction in aging happening simultaneously and being related is questioned and with this article, we aim to clarify this possible relationship. Thus, the objectives of this study were to verify whether there is age-related vestibular dysfunction and to test the association of vestibular dysfunction with presbycusis in the elderly population.

MATERIAL AND METHODS

Participants

We performed a retrospective analytical cross-sectional study, carried out with patients who were followed in vertigo consultation at the Otorhinolaryngology department of a tertiary-level hospital who underwent a VNG and complete audiometric evaluation due to nonspecific vestibular complaints, without a specific vestibular disorder diagnosis (e.g., Meniere’s disease or vestibular migraine, based on standard diagnostic criteria) and with a normal otoneurological examination (which excludes BPPV).14,15

Patients were selected and divided into two groups: A group of patients older than 60 years (group A) and another group of patients between the ages of 18 and 50 years (group B), to get a sample size larger than the one calculated in the OpenEpi® program, using as reference a consensus published by Yuri Agrawal et al.16 in 2019. Age grouping cutoff of 60 years was considered, based on the published guidelines by the World Health Organization.17 Exclusion criteria included patients with previously documented hearing loss; with a history of taking ototoxic drugs, recurrent middle ear infections, chronic noise exposure, family history of sensorineural hearing loss (NSHL), traumatic brain injury, stroke, neurological diseases; with an asymmetric NSHL; with unilateral vestibular hypofunction; with diagnosed central or peripheral vestibular disease, and patients who performed VNG and audiometric study in two distinct times. A total sample size of 80 patients was included in the study, with 40 patients in each group.

Examinations

In both groups, for assessing vestibular function, we used caloric tests. For the calculation of the total caloric response (TCR), we summed the bithermal maximum peak of slow-phase velocity (SPV) of the nystagmus on each side. Bilateral vestibular weakness (bilateral vestibulopathy) was considered if the TCR was <12°/s.18,19 Mild bilateral peripheral vestibular hypofunction (one of the diagnostic criteria for presbyvestibulopathy) was set when the sum of bithermal maximum peak of SPV on each side was between 6 and 25°/s.16

The audiometric evaluation was performed using the pure-tone audiometry, with the analysis of bone conduction (BC) thresholds at
frequencies of 500, 1000, 2000, 4000, and 8000 Hz. We computed the pure tone average (PTA) of BC hearing thresholds at 500, 1000, 2000, and 4000 Hz. BC thresholds at 8000 Hz were considered to assess high-frequency hearing loss.

**Statistical methods**

Descriptive and inferential statistical analyses were performed using the Statistical Package for the Social Sciences program (SPSS®), version 26.

Data were reported as mean (M) and standard deviation (SD) for quantitative variables and the comparison of these variables between the two participant groups was done using Student’s t-test. The proportions of categorical variables between the two groups were analyzed using the chi-square test. To analyze the intensity and direction of the linear relationship between two continuous variables, Pearson’s correlation coefficient (r) was used. As described by Chan, a correlation coefficient of less than 0.3 was considered weak, 0.3–0.6 reasonable, 0.6–0.8 strong and 0.8–1 very strong.

The 95% confidence intervals (CI) are reported. Significance was settled for \( P < 0.05 \). Patient privacy and data confidentiality were guaranteed.

Ethical approval for this project was obtained by the local ethics commission.

**RESULTS**

**Auditory function evaluation**

The mean age in group A was (70.0 ± 7.6) years, while it was (36.6 ± 8.1) years in group B. Regarding the auditory function, mean BC thresholds at all pure-tone audiometry frequencies were significantly higher in group A \( (P < 0.001) \) compared to group B, as shown in Table 1.

Additionally, there was a very strong and positive correlation \( (r = 0.809, P < 0.001) \) between age and PTA of BC hearing thresholds.

**Vestibular function evaluation**

We calculated the mean TCR in both groups and found that, although the mean TCR is lower in group A \( (M = 28.43°/s, SD = 19.60°/s) \), the differences between both groups were not statistically significant (group B: \( M = 33.00°/s, SD = 21.06°/s, P > 0.05 \)). There were also no differences between groups \( (P > 0.05) \) when considering mild bilateral peripheral vestibular hypofunction (TCR between 6 and 25°/s), with group A having a prevalence of 53%.

However, after applying the definition of bilateral vestibular weakness (TCR < 12°/s) we found that the prevalence was statistically different \( (P < 0.05) \) between groups (group A: 22.5%; group B: 5.0%) (Figure 1). At the same time, there was a reasonable negative correlation \( (r = −0.314, P < 0.05) \) between TCR and age in group A.

**Relationship between auditory and vestibular function**

When both groups were analyzed together, we did not find a correlation between the PTA of BC hearing thresholds and the TCR. However, in group A, we obtained a reasonable negative and statistically significant correlation \( (r = −0.320, P < 0.05) \) between the mean BC thresholds at high frequencies and TCR (Figure 2). In this context, 10.3% of the variance of caloric tests in patients older than

| TABLE 1 | Mean bone conduction thresholds at all pure-tone audiometry frequencies in both groups (dB, mean ± SD) |
|---------|---------------------------------------------------------------|
| Group   | n    | 500 Hz        | 1000 Hz       | 2000 Hz       | 4000 Hz       | 8000 Hz       | 500–8000 Hz   |
|---------|------|---------------|---------------|---------------|---------------|---------------|---------------|
| Group A | 40   | 15.06 ± 5.84  | 17.25 ± 8.60  | 23.19 ± 12.87 | 30.31 ± 14.72 | 41.19 ± 15.16 | 25.40 ± 9.74  |
| Group B | 40   | 9.25 ± 3.89   | 7.56 ± 4.10   | 8.63 ± 5.16   | 9.06 ± 6.47   | 11.38 ± 7.88  | 9.18 ± 4.60   |
| t test  |      | −5.238        | −6.430        | −6.642        | −8.357        | −11.035       | −9.524        |
| P value |      | <0.001        | <0.001        | <0.001        | <0.001        | <0.001        | <0.001        |
60 years can be explained by the variance in mean BC hearing thresholds at high frequencies in this group ($r^2 = 0.103$).

Additionally, we found that, in both groups, there was a positive, but weak, statistically significant correlation ($r = 0.232$, $P < 0.05$) between PTA of BC hearing thresholds and the presence of bilateral vestibular weakness (TCR < 12°/s).

**DISCUSSION**

**Age-related vestibular dysfunction**

There are many published studies regarding the prevalence of vertigo, dizziness, balance disorders, and its associated consequences in the elderly. In a review, 65% of people over 60 years experience daily dizziness or loss of balance, highlighting the importance of deepening our knowledge and understanding in this topic.

It is already established that with aging there is a significant and progressive degeneration in almost all types of cells of the vestibular system, including the hair cells of the macula and the crista ampullaris, the nerve fibers of the vestibular nerve, the cells contained in Scarpa’s ganglion and the neurons of the vestibular nuclei, thus affecting both the peripheral and central vestibular system. Most published studies agree that this cellular degeneration is more pronounced in the seventh and eighth decades of life, which corresponds to the age group where complaints of nonspecific vertigo, instability, and loss of balance are more prevalent. In this context, the terms presbyvertigo and presbyvestibulopathy have been used to describe these changes related to the aging of the vestibular system. The diagnosis of presbyvestibulopathy, as proposed in the consensus document of the classification committee of the Bárány Society (Table 2), aims to cover subtle or incomplete vestibular losses attributable to the normal aging process, similar to other age-related sensory losses, such as presbycusis or presbyopia, which are equally incomplete.

In this study, the mean TCR was lower in group A with patients older than 60 years (vs. the group with patients aged between 18 and 50 years), however, this difference between groups was not statistically significant. There were also no differences between groups after applying one of the criteria defined by the Bárány society for mild bilateral peripheral vestibular hypofunction (TCR between 6 and 25°/s). Additionally, in group A only 53% of patients met all the criteria in Table 2.

Curiously, there was a statistically significant difference between groups in the prevalence of bilateral vestibular weakness (bilaterial vestibulopathy; TCR < 12°/s), with a prevalence of 22.5% in group A. Furthermore, we found that in group A, the increase in age is negatively correlated with mean TCR. This data suggests that, in

**TABLE 2** Diagnostic criteria for presbyvestibulopathy

| A. Chronic vestibular syndrome (at least 3 months duration) with at least 2 of the following symptoms: |
|-----------------------------------------------|
| 1. Postural imbalance or unsteadiness |
| 2. Gait disturbance |
| 3. Chronic dizziness |
| 4. Recurrent falls |

| B. Mild bilateral peripheral vestibular hypofunction documented by at least 1 of the following: |
|-----------------------------------------------|
| 1. VOR gain measured by video-HIT between 0.6 and 0.8 bilaterally |
| 2. VOR gain between 0.1 and 0.3 upon sinusoidal stimulation on a rotatory chair (0.1 Hz, Vmax = 50–60°/s) |
| 3. Reduced caloric response (sum of bithermal maximum peak SPV on each side between 6 and 25°/s) |

| C. Age ≥ 60 years |

| D. Not better accounted for by another disease or disorder |

Abbreviations: HIT, head impulse test; VOR, vestibulo-ocular reflex.
patients older than 60 years, an increase in age leads to a significant decrease in mean TCR.

These results agree with the findings of similar studies, although these same studies refer to the 1990s.24 Since then, studies of the impact of vestibular aging on caloric tests are scarce.5 However, secondary to the deterioration of the epithelium of the macula and crista ampullaris, as previously discussed, other changes in the VNG may occur which, although they have not been the subject of this investigation, should be taken into account when considering presbyvestibulopathy. Therefore, in the review article carried out by Zalewski,9 a study is mentioned where they compared healthy young people (19–32 years) and elderly people (65–77 years) and concluded that smooth pursuit tracking can be influenced by age, characterized by a reduction in pursuit gain (measure the relationship between eye velocity and the stimulus) and an increase in pursuit initiation latency for elderly individuals.25 It is speculated that the decline in pursuit function is likely to be secondary to cerebral cortical atrophy, loss of cerebellar Purkinje cells, and degeneration of extraocular muscle tissue. This age-related impairment also extends to saccadic movements and optokinetic nystagmus. However, the same authors pointed out that there was an interpersonal variability in these parameters, and these changes may not always be present with aging. Additionally, this epithelial dysfunction may also contribute to the greater incidence of changes in positioning tests, such as in the Dix-Hallpike test as well can justify the high prevalence of BPPV in adults older than 60 years (approximately seven times higher compared to adults aged between 18 and 39 years).3,6

Nevertheless, although some tests, such as caloric tests and the clinical head impulse test, are very sensitive in identifying a marked vestibular dysfunction, these may not be sensitive enough to identify a slight and incomplete decline in age-related vestibular dysfunction which may justify the absence of significant differences in the analysis between our two groups.4 Another justification for these results may be related to the small sample size of our study.

Relationship between auditory and vestibular aging

Regarding our second goal, the results demonstrate that in people older than 60 years, there is a negative and statistically significant correlation between mean BC thresholds at high frequencies (8000 Hz) and TCR. So, 10.3% of the variability of TCR in the elderly is explained by the variation in BC hearing thresholds at high frequencies: the higher the mean BC thresholds at high frequencies, the lower the response tends to be in caloric tests and, consequently, the greater degree of vestibular hypofunction. We also found that, in both age groups, there is a positive correlation between PTA of BC hearing thresholds and the presence of bilateral vestibular weakness.

The truth is that, although different, there seems to be a similar functioning between the vestibular and auditory systems, and when one is dysfunctional, the other may also present some degree of impairment.12,26 This relationship has been previously documented in some studies, although in limited numbers. One of the studies was developed by Abd El-Salam et al.12 who analyzed the relationship between auditory and vestibular function in a study group, consisting of 20 patients aged between 50 and 75 years without any vestibular symptoms or diagnosed vestibular diseases and with the diagnosis of mild to moderate bilateral sensorineural hearing loss, and compared them to a control group of 20 healthy individuals in the same age range but with normal hearing. To assess auditory function, they analyzed auditory brainstem responses (ABR) and, the vestibular function was assessed, essentially, using vestibular evoked myogenic potential (VEMP). In this study, it was concluded that the study group had statistically significant differences in absolute peak latencies of ABR waves I, III, and V, without differences in interpeak latencies, and that the same group had significantly prolonged P13 and N23 latencies in VEMP as well as a significantly reduced amplitude of P12-N23 compared to the control group. This study provides extra insight into the relationship between a subclinical peripheral vestibular deficit and presbycusis. Similar results were also obtained by Kutarana et al.27 who stated that pathologies that affect a part of the inner ear may have repercussions on other structures with the same embryological origin. Studies in animal models of C57BL/6 rats, considered to represent the animal model with age-related hearing loss, reported a 30% decline in hair cell density in horizontal semicircular canals, being this decline age-related. Thus, and considering the results of this study, an association between presbycusis and vestibular dysfunction is highly possible, in the absence of other systemic and inner ear pathologies that may be the cause of vestibular dysfunction.6

Despite advances in clinical diagnoses, the functional impact that an aged vestibular system has on the activities of a patient’s daily life, such as standing and walking, remains largely unknown.5 Regardless of the functional impact, what is known is that dizziness and imbalance in the elderly represent an increasing public health concern, since they increase the risk of accidental falls in this age group, with associated morbidity and mortality.6 Additionally, it is also important to screen for age-related hearing loss in the elderly due to its established relationship with cognitive decline and depression.28

Vestibular rehabilitation proved to be useful in improving postural control and dizziness symptoms in patients with age-related imbalance.16 The American Geriatrics Society states that balance exercises in standing are particularly beneficial for older people at risk for falling.1 In a study performed with 240 patients older than 70 years, Jung et al.29 concluded that vestibular rehabilitation was effective in reducing dizziness, even in patients without a specific diagnosis of vestibular disorder. Other simple measures that may have an impact on reducing the risk of fall in older individuals are the reduction of orthostatic hypotension, the control, and reduction of medications that may cause balance-related symptoms, the improvement of visual acuity with appropriate glasses, the encouragement of night and safety lights, the use of geriatric assistive devices such as walking sticks, the practice of exercise and the use of appropriate footwear.1 To date and based on the current knowledge, there are no specific pharmacological treatments to improve age-related deterioration of vestibular function.
**Limitations and future directions**

There are several limitations to this study worthy of discussion. Firstly, we must consider the fact that patients in both age groups are symptomatic and the identified differences, or their absence, in TCR or in the prevalence of mild bilateral peripheral vestibular hypofunction reported in this paper may be attributable to factors other than age. So, although we included a young control group with the same characteristics (also symptomatic), it is not known to what degree our findings reflect that the older group has vestibular pathology that is causing their symptoms or if the vestibular alterations reflect normal aging that is bothersome. Another explanation for the absence of significant differences in the mean TCR between both groups may be related to the fact that the age-related vestibular changes compromise, preferably, the tests that analyze the high-frequency vestibular activity (e.g., Video Head Impulse Test) which is not verified in the caloric tests since they stimulate the vestibular system below its physiological frequency. Secondly, the generalizability of our results is limited by the fact that caloric tests do not evaluate the complete vestibular system, testing only the function of the lateral semicircular canal. Future studies should consider other tests (e.g., cVEMP, oVEMP, vHIT, chair tests) that assess the remaining components of the vestibular system, such as the saccule, utricle, and vestibular nerve, to understand more exactly how the normal aging process affects the vestibular system. Additionally, computerized dynamic posturography (CDP) assesses the interaction of the three fundamental balance systems for maintaining postural balance (visual, vestibular, and somatosensory) and, although less specific than VNG, CDP provides a more global view of the capacity of maintaining balance under more challenging environmental circumstances. Therefore, it has not only diagnostic but also therapeutic importance in the management of vestibular pathology. Furthermore, as previously mentioned, it would also be important to reproduce the same study in a larger sample size with asymptomatic patients to see the reproducibility of our results.

**CONCLUSIONS**

With this study, we aimed to contribute to the scarce recent literature that evaluates the effect of aging on the inner ear organs, to understand if there is a relationship between presbyvestibulopathy and presbycusis. Our results indicate that in patients older than 60 years with hearing loss at high frequencies, typically seen in the early stages of presbycusis, it appears to be a greater deterioration of responses in caloric tests. The anatomical, physiological, and histological similarities between the cochlear and vestibular systems may explain the relationship between presbycusis and age-related vestibular dysfunction. Thus, in patients with hearing loss, it is essential to conduct a complete vestibular study to diagnose vestibular disorders and, consequently, prevent adverse outcomes that may result from these alterations.

**AUTHOR CONTRIBUTIONS**

Cátia Azevedo: Conceptualization, software, formal analysis, writing – original draft. Sérgio Vilarinho: Conceptualization, methodology; Ana Sousa Menezes: Writing – review & editing, supervision, validation; Fernando Milhazes Mar: Writing – review & editing; Luís Dias: Validation.

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Not applicable.

**CONFLICTS OF INTEREST**

The authors declare no conflicts of interest.

**DATA AVAILABILITY STATEMENT**

The analyzed data during the current study are available from the corresponding author on reasonable request.

**ETHICS STATEMENT**

This work was approved by the local ethics committee.

**REFERENCES**

1. Furman JM, Raz Y, Whitney SL. Geriatric vestibulopathy assessment and management. *Curr Opin Otolaryngol Head Neck Surg*. 2010;18(5):386-391. doi:10.1097/MOO.0b013e32833ce5a6
2. Hansson EE, Månsso NO, Håkansson A. Assessment and management of vertigo and dizziness among older persons. *Rev Clin Gerontol*. 2004;14(3):229-234. doi:10.1017/S0959259805000156
3. Jitsukawa S, Takano K, Ito F, Tsubomatsu C, Himi T. Influence of age on caloric response. *Adv Otorhinolaryngol*. 2016;77:17-22. doi:10.1159/000441864
4. Anson E, Jeka J. Perspectives on aging vestibular function. *Front Neurol*. 2016;6:269. doi:10.3389/fneur.2015.00269
5. Zalewski CK. Aging of the human vestibular system. *Semin Hear*. 2015;36(3):175-196. doi:10.1055/s-0035-1555120
6. Iwasaki S, Yamasoba T. Dizziness and imbalance in the elderly: age-related decline in the vestibular system. *Aging Dis*. 2015;6(1):38-47. doi:10.14336/AD.2014.0128
7. Mangabeira Albernaz PL. Vertigo in elderly patients: a review of 164 cases in Brazil. *Ear Nose Throat J*. 2014;93(8):322-330. doi:10.1177/014556131409300810
8. Jahn K. The aging vestibular system: dizziness and imbalance in the elderly. *Adv Otorhinolaryngol*. 2019;82:143-149. doi:10.1159/000490283
9. Arshad Q, Seemungal BM. Age-related vestibular loss: current understanding and future research directions. *Front Neurol*. 2016;7:231. doi:10.3389/fneur.2016.00231
10. Mekki S. The role of videonystagmography (VNG) in assessment of dizzy patient. *Egypt. J Otolaryngol*. 2014;30(2):69.
11. Relis LR, Escada P. Presbycusis: do we have a third ear. *Braz J Otorhinolaryngol*. 2016;82(6):710-714. doi:10.1016/j.bjorl.2015.12.006
12. Abd El-Salam GMS. The relationship between presbycusis and vestibular activity. *J Med Sci Res*. 2018;14(4):245-249.
13. Cruickshanks KJ, Tweed TS, Wiley TL, et al. The 5-year incidence and progression of hearing loss: the epidemiology of hearing loss study. *Arch Otolaryngol Head Neck Surg*. 2003;129(10):1041-1046. doi:10.1001/archotol.129.10.1041
14. Lopez-Escamez JA, Carey J, Chung WH, et al. Diagnostic criteria for Meniere’s disease. Consensus document of the Bârány Society, the Japan Society for Equilibrium Research, the European Academy of Otolaryngology and Neurotology (EAONO), the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) and the Korean Balance Society. *Acta Otorhinolaringol Esp*. 2016;67(1):1-7. doi:10.1016/j.otorri.2015.05.005
15. Lempert T, Olesen J, Furman J, et al. Vestibular migraine: diagnostic criteria. J Vestib Res. 2012;22(4):167-172. doi:10.3233/VES-2012-0453
16. Agrawal Y, Van de Berg R, Wuyts F, et al. Presbyvestibulopathy: Diagnostic criteria Consensus document of the classification committee of the Bárány Society. J Vestib Res. 2019;29(4):161-170. doi:10.3233/VES-190672
17. World Health Organization. Integrated Care for Older People: Guidelines on Community-Level Interventions to Manage Declines in Intrinsic Capacity. WHO; 2017.
18. Hain TC, Cherchi M, Yacovino DA. Bilateral vestibular weakness. Front Neurol. 2018;9:344. doi:10.3389/fneur.2018.00344
19. Strupp M, Kim JS, Murofushi T, et al. Bilateral vestibulopathy: diagnostic criteria Consensus document of the Classification Committee of the Bárány Society. J Vestib Res. 2017;27(4):177-189. doi:10.3233/VES-170619
20. Chan YH. Biostatistics 104: correlational analysis. Singapore Med J. 2003;44(12):614-619.
21. Maes L, Dhooge I, D’haenens W, et al. The effect of age on the sinusoidal harmonic acceleration test, pseudorandom rotation test, velocity step test, caloric test, and vestibular-evoked myogenic potential test. Ear Hear. 2010;31(1):84-94. doi:10.1097/AUD.0b013e3181b9640e
22. Jang YS, Hwang CH, Shin JY, Bae WY, Kim LS. Age-related changes on the morphology of the otoconia. Laryngoscope. 2006;116(6):996-1001. doi:10.1097/01.mlg.0000217238.84401.03
23. Waltcher LE, Westhofen M. Presbyvertigo-agining of otoconia and vestibular sensory cells. J Vestib Res. 2007;17(2-3):89-92.
24. Calder J. Aging and the balance control systems. In: Weinstein BE, ed. Geriatric Audiology. Thieme; 2000: 141-167.
25. Ventura DdeFP, Ganoato L, Mitre EI, Mor R. Oculomotoric parameters in digital nystagmography among children with and without learning disorders. Braz J Otorhinolaryngol. 2009;75(5):733-777.
26. Santos TGT, Venosa A, Sampaio ALL. Association between hearing loss and vestibular disorders: a review of the interference of hearing in the balance. Int J Otolaryngol Head Neck Surg. 2015;4(3):173-179.
27. Kurtaran H, Acar B, Ocak E, Mirici E. The relationship between senile hearing loss and vestibular activity. Braz J Otorhinolaryngol. 2016;82(6):650-653. doi:10.1016/j.bjorl.2015.11.016
28. Slade K, Plack CJ, Nuttall HE. The effects of age-related hearing loss on the brain and cognitive function. Trends Neurosci. 2020;43(10):810-821. doi:10.1016/j.tins.2020.07.005
29. Jung JY, Kim JS, Chung PS, Woo SH, Rhee CK. Effect of vestibular rehabilitation on dizziness in the elderly. Am J Otolaryngol. 2009;30(5):295-299. doi:10.1016/j.amjoto.2008.06.013
30. Mezzalira R, Bitar RSM, do Carmo Bilécki-Stipsky MM, Brugnera C, Grasel SS. Sensitivity of caloric test and video head impulse as screening test for chronic vestibular complaints. Clinics. 2017;72(8):469-473. doi:10.6061/clinics/2017(08)03

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