Hearing as an Independent Predictor of Postural Balance in 1075 Patients Evaluated for Dizziness

Jan Erik Berge, MD [123], Stein Helge Glad Nordahl, MD, PhD [13], Hans Jørgen Aarstad, MD, PhD [23], Frederik Kragerud Goplen, MD, PhD [123]

1: Norwegian National Advisory Unit on Vestibular Disorders, Haukeland University Hospital, Bergen, Norway.

2: Department of Otorhinolaryngology & Head and Neck Surgery, Haukeland University Hospital, Bergen, Norway

3: Department of Clinical Medicine, University of Bergen, Bergen, Norway

Corresponding author: Jan Erik Berge, MD, Department of Clinical Medicine, University of Bergen, Department of Otorhinolaryngology & Head and Neck Surgery, Haukeland University Hospital, N-5021 Bergen, Norway. E-mail: jan.erik.berge@helse-bergen.no Phone: +49 55 97 50 00

Indexing keywords: Postural balance, hearing, dizziness, vertigo, hearing loss, postural control, falls, imbalance, aging, presbyacusis, presbyastasis, sensory reweighting, vestibular disease, posturography, stabilometry.

Preliminary results were presented at the 2018 AAO-HNSF Annual Meeting and OTO Experience; October 7-10, 2018 Atlanta, Georgia.

Abstract

Objective: To evaluate the association between hearing and postural balance.

Study design: Retrospective cross-sectional study.

Setting: Tertiary care otolaryngology clinic.

Subjects and methods: Patients examined for suspected vestibular disorder were included in this study. The outcome variable was postural sway measured by static posturography during quiet standing with eyes closed. The predictor variable was pure tone average hearing threshold on the best hearing ear at 0.5, 1, 2 and 3 kHz. Covariates were age, sex and vestibular disease or vestibular asymmetry assessed by bi-thermal caloric irrigation.

Results: 1075 patients were included. Increased hearing threshold was a strong predictor of increased postural sway (path length) after correcting for age and sex. A 10 dB increase in hearing loss on the best hearing ear predicted a mean increase of 6.0% increase in path length (CI: 2.9%; 9.3%, $p<0.001$). Of the covariates, increasing age ($p<0.001$) and male gender ($p=0.009$) were significant predictors of increased postural sway. The effect of increased hearing threshold was also significant after adjusting for vestibular disease.

Conclusion: Increased hearing threshold was an independent predictor of increased postural instability, and this effect was strongest for the best hearing ear. Unilateral vestibular disease did not seem to explain this association between hearing and postural balance. Reduced hearing is associated with impaired balance, and interventions to prevent falls should be considered for patients at risk.

Introduction

Symptoms of dizziness, imbalance and reduced hearing affect people of all age groups and constitute approximately 10% of office visits in otolaryngology[1]. Hearing loss ranks as the third leading cause for years lived with disability world wide[2], and 5% of children and 20 % of elderly will experience balance problems or dizziness during one year[3,4]. The organs of hearing and equilibrium are closely linked anatomically and physiologically, and many diseases, such as Ménière's disease and vestibular schwannoma, affect both systems simultaneously. Therefore, an association between hearing and balance may be expected. However, while hearing loss is usually caused by diseases of the ear[5], there is a wide range of diseases causing impaired balance. This includes pathologies in various organ systems, such as the vestibular, visual, proprioceptive, musculoskeletal, central, and peripheral nervous systems[6,7].

Two recent systematic reviews address the association between hearing and postural control. Agmon et al. found support for a correlation between hearing loss and reduced postural control in older adults[8], but vestibular and neurologic patients were excluded from this review. There was furthermore a large variability in methods of measuring postural balance and hearing level. Jiam and Agrawal concluded in their review that hearing loss was associated with a doubled risk for falling among older persons[9]. Vestibular disorders and vestibular function were not assessed in any of the studies included in these reviews. Both systematic reviews point to the unknown causality and mechanisms between hearing loss and postural control, therefore future studies with objective measurements of hearing[8,9] and vestibular function[9] were recommended.

The aim of this study was to evaluate whether hearing loss is an independent predictor of postural imbalance among patients evaluated for dizziness. To assess the effect of unilateral inner ear disorders, such as Ménière’s disease and vestibular schwannoma, we aimed to analyze hearing on the two ears separately and adjust for vestibular asymmetry.

Methods

Design, setting and subjects

This is a retrospective cross-sectional study conducted at the Department of otorhinolaryngology in a tertiary care academic hospital. Consecutive patients referred due to suspected vestibular disorders over a time span of 12 years were considered for inclusion. The majority of patients were seen in an outpatient setting. A resident or consultant in otorhinolaryngology diagnosed each patient. Two of the coauthors (FKG, SHGN) later reviewed the diagnoses. Diagnostic criteria of vestibular migraine[10] was not published at the initiation of the study and patients thought to have migraine as a cause of dizziness were therefore categorized with non-vestibular cause for dizziness. For patients with several diagnoses, only the main vestibular diagnosis was used in analysis. Inclusion criteria were the availability of audiometric and posturography data.

Ethics

The study was approved by the Regional Committee for Medical and Health Research Ethics of Western Norway (2012/1075). All subjects alive at the time of follow-up were informed about the study by mail and given the opportunity to withdraw.

Postural balance

Static posturography was performed using a commercially available platform (Cosmogamma®, AC International, Cento, Italy). The platform measures 40 x 40 x 8 cm and contains three strain gauge pressure transducers connected to a computer that calculates the center of pressure (COP) with a sampling frequency of 10 Hz. Testing was performed under standardized conditions in a quiet room with the patients standing with heels 7 cm apart on a firm surface and arms along the side. Recordings were performed over 60 seconds, first with eyes open and then repeated with eyes closed. Static posturography was performed prior to electro-/videonystagmography and caloric tests in order not to induce postural instability. The path length in millimeters described by the COP during the 60 seconds of testing was recorded and used for analysis. Path lengths may vary from zero, a theoretical value representing an immobile subject, to several thousands. The Romberg quotient (RQ) is the ratio between path length with eyes closed (EC) and eyes open (EO) represented by the formula RQ = EC : EQ[11].

Hearing

Audiometry was performed in sound-insulated booths by trained audiologists. Pure tone average (PTA in dB_{HL}) for air conduction was calculated from the frequencies 0.5, 1, 2 and 3 kHz. When the threshold at 3 kHz was missing, the average of the thresholds at 2 and 4 kHz was used as recommended by the Hearing Committee of the American Academy of Otolaryngology-Head and Neck Surgery[12]. Grades of hearing impairment were reported according to the classification by the World Health Organization (WHO)[13].

Bithermal caloric testing

The caloric response (maximum slow phase velocity of nystagmus) to warm and cold water (44 and 30 degrees centigrade) irrigation was recorded using electro- or videonystagmography. Asymmetry between the two ears was calculated using Jongkees' formula, and asymmetry $\geq 25\%$ was considered significant[14].

Statistical analyses

Path lengths and Romberg quotients were positively skewed and logarithmic transformations were performed before t-tests, ANOVA, test of Pearson's correlation coefficient, and regression analysis. Multiple imputations using multivariate normal distribution with 50 imputations were used for multivariate regression analyses including variables with missing data (caloric testing and comorbidities). All statistical analyses were performed using Stata (StataCorp. 2015. Stata Statistical Software: Release 15. College Station, TX: StataCorp LP.). Two-sided p-values < 0.05 were considered significant.

Results

Of the 1218 patients eligible for the study, 143 were excluded due to missing consent. Among the 1075 included in the study, 218 patients had missing information on caloric response, and 161 had missing information regarding comorbidities. 442 (41.1%) were male, the mean age was 50.7 years (SD 15.7). The most common diagnoses were Ménière's disease (14.4%) followed by Benign Paroxysmal Positional Vertigo (BPPV) (10.4%) and vestibular neuritis (9.4%). Among the 914 patients with data regarding comorbidities, 139 (15.2%) reported hypertension, 26 (2.8%) reported former stroke or transient ischemic attack (TIA), 27 (3.0%) reported diabetes mellitus and 61 (6.7%) reported heart disease. 657 patients (61%) reported time since the first attack of dizziness with a median time of 392 days, ranging from 12 hours until 45 years.

Hearing and posturography results by diagnosis are presented in Table 1 with corresponding p-values for ANOVA. The association between postural sway and WHO grade of hearing loss is presented in Figure 1. WHO grade 0 (normal hearing) was found in 832 patients

(77.4%). Grade 1 hearing loss was found in 142 patients (13.2%). WHO Grade 2 or worse hearing was found in 101 patients (9.4%). The latter groups were combined due to the low number of patients with grade 3 and 4 hearing loss (8 and 4 patients respectively).

Regression analysis adjusting for age and sex found that a 10 dB increase in hearing loss on the best hearing ear was associated with a 6.0% increase in path length with eyes closed (95% CI: 2.9%; 9.3%, $p<0.001$). A 10-year increase in age corresponded to a 6.8% increase in path length with eyes closed (95% CI: 3.9%, 9.9%, $p<0.001$). Women had 9.9% shorter path length with eyes closed compared to men in this model (95% CI: 2.6%, 16.7%, $p<0.009$). A 10dB increase in PTA on the worst hearing ear was associated with a 2.0% (95% CI: 0%; 4.1%, $p=0.040$) increase in path length with eyes closed. Regression coefficients from crude and adjusted analysis for the log transformed path length with eyes closed are presented in Table 2. In regression analysis adjusted for hearing, sex and age, vestibular asymmetry > 25% was not significantly associated with path length in analyses adjusted for neither the best nor the worst hearing ear ($p=0.884$, $p=0.981$).

There was no significant association between comorbidities and postural balance after adjusting for age, sex and hearing level (Table 3). Postural sway was associated with hearing level after adjustment for clinically assigned diagnoses, age and sex (Table 4). In these analyses a 10dB increase in hearing loss on the best hearing ear was associated with a 7.3% increase in path length (4.14%;10.7%, $p<0.001$) and a 10dB increase on the worst hearing ear with a 4.0% increase in path length (1.89%; 6.17%, $p<0.001$) with eyes closed. Analysis stratified for age (table 5) showed a persistent association between hearing and postural balance in the youngest (quantile) age group.

Discussion

This study demonstrated that hearing loss is associated with postural imbalance. The association was strongest for the best hearing ear, and the effect of a 10 dB increase in hearing loss was comparable to a 10-year increase in age.

Former studies have found an association between hearing and balance in the general population, but to the best of our knowledge, this is the first study conducted on a large population of patients evaluated for vestibular disease.

We found that the best hearing ear was the ear most strongly associated with postural balance. It is well known that patients with acute vestibular loss will experience increased sway[15]. However, balance tends to improve as the loss is compensated[16] and proprioceptive information is regarded as the most important sensory input in static conditions with eyes closed[17]. Most of the patients in this cohort had a long duration of symptoms and our findings indicate that a chronic asymmetric vestibular function is not associated with decreased postural balance. Furthermore, vestibular schwannoma and Ménière's disease are associated with a deterioration of both hearing and vestibular function on the affected ear. Therefore, one would expect the hearing on the worst hearing ear to be of greatest importance if these diseases caused impaired balance, this was however not the finding in the present study. Our findings that it is the best hearing ear that best predicts postural balance supports the interpretation that the association between hearing and postural balance is not mainly caused by unilateral diseases of the labyrinth.

It has been hypothesized that patients with hearing impairment use much of their cognitive capacity on hearing and therefore have less capacity for balance related tasks[9,18]. This has been supported by reports that attention and cognitive processes influences postural control, but the effect was most important among older persons and in challenging balance situations[19]. Our findings with a strong relationship between hearing and balance among the youngest patients and on a simple balance task, indicated that the effect of cognitive load could not explain the association between hearing and postural balance in this study.

It has also been reported that auditory cues influence postural balance[20,21,22], and the use of cochlear implants or hearing-aids have been associated with improved balance[23,24,25]. However, in our study, testing was performed in a quiet environment and we do not expect ambient noise to affect the results significantly. This is supported by the study performed by Kanegaonkar et al. where there was no difference between balance testing with eyes closed in a soundproof room and in a regular clinic room[26], but more studies with testing in soundproof environment or with ear defenders are warranted to confirm this.

In analyses adjusted for age, sex and diagnoses, we found that patients considered by the clinician to have a cerebrovascular cause for dizziness had impaired balance. There was no significant association between self-reported cerebrovascular risk factors, such as diabetes mellitus, hypertension, previous stroke and heart disease, and postural balance in adjusted analysis. However, this study does not necessarily exclude such a relationship, as has been reported in previous studies[16,27].

The association between hearing and postural balance in the youngest age group may indicate a high relevance of genetic and environmental factors present in early life. Additionally, approximately half of hearing losses among younger patients are reported to have a genetic etiology[28] and an increasing number of genes associated with both hearing loss and vestibular function are described[29]. The present study did not include data to evaluate the role of genetics, but this would be relevant for future studies.

The main strength of this study is the large population consisting of patients with accurate testing of both hearing and postural balance as well as assessment of vestibular disease, vestibular function and comorbidities. Caloric testing is the most commonly used vestibular test to exclusively assess one side, and it provides quantification of unilateral vestibular disease by stimulating the horizontal semicircular canal[14,30,31]. The study also has possible limitations. Since the study included patients examined for dizziness of suspected vestibular origin, generalizability of the results to the general population is not determined. Additionally, the present study focused on unilateral vestibular disease, and vestibular asymmetry. Further studies are necessary in order to determine whether the results are also valid for bilateral vestibulopathies. Recently, diagnostic criteria for bilateral vestibulopathy have been published[31] and the estimated prevalence is reported to be 28 per 100 000 adults[32]. Future studies should therefore preferably include measures that are sensitive to bilateral vestibular loss, such as video head impulse testing (v-HIT) of all semicircular canals, cervical Vestibular Evoked Myogenic Potentials (cVEMP) and ocular VEMP (oVEMP). Another limitation of the study is that patients were included prior to the publication of diagnostic criteria of vestibular migraine[10]. Consequently classifications of such patients were not rigorous throughout the study period, and patients suspected of having vestibular migraine were therefore included with "Other non-vestibular disease" in the analyses. However, we do not expect this to affect the conclusions of the present study regarding physical measurements of balance and hearing as this was independent of clinical diagnoses.

In conclusion, postural imbalance was associated with hearing loss in the present study, particularly on the best hearing ear. Unilateral vestibular disease did not seem to explain this association between hearing and postural balance. The myriad of potential causes for reduced balance further complicates the process of establishing a causal relationship, but this study advocates further investigations that considers genetic factors and incorporates comprehensive evaluation of bilateral vestibular function. Findings from this study have clinical importance for the large group of patients diagnosed with hearing loss. Health care professionals, in particular otolaryngologists and audiologists, should be aware of the association between hearing loss and reduced postural balance. Preventive measures for falls are effective[33], and should be considered for many patients with hearing impairment.

References

1. Schappert S, Nelson C. Schappert SM, Nelson C. National Ambulatory Medical Care Survey, 1995–96 Summary. *Vital Heal Stat*. 1999;13(142):i-vi,1-122

2. Vos T, Abajobir AA, Abate KH, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *Lancet*. 2017;390(10100):1211-1259.

3. Lin HW, Bhattacharyya N. Balance disorders in the elderly: Epidemiology and functional impact. *Laryngoscope*. 2012;122(8):1858-1861.

4. Li C-M, Hoffman HJ, Ward BK, Cohen HS, Rine RM. Epidemiology of dizziness and balance problems in children in the United States: A population-based study. *J Pediatr*. 2016;171:240-7.e1-3.

5. Graydon K, Waterworth C, Miller H, Gunasekera H. Global burden of hearing impairment and ear disease. *J Laryngol Otol*. 2018;(1984):1-8.

6. Jacobson GP, McCaslin DL, Piker EG, Gruenwald J, Grantham S, Tegel L. Insensitivity of the "Romberg test of standing balance on firm and compliant support surfaces" to the results of caloric and VEMP tests. *Ear Hear*. 2011;32(6):e1-5.

7. Paillard T, Noé F. Techniques and methods for testing the postural function in healthy and pathological subjects. *Biomed Res Int*. 2015;2015:891390.

8. Agmon M, Lavie L, Doumas M. The association between hearing loss, postural control, and mobility in older adults: A systematic review. *J Am Acad Audiol*. 2017;28(6):575-588.

9. Jiam NT-L, Li C, Agrawal Y. Hearing loss and falls: A systematic review and meta-analysis. *Laryngoscope*. 2016;126(11):2587-2596.

10. Lempert T, Olesen J, Furman J, et al. Vestibular migraine: Diagnostic criteria. *J. Vestib. Res*. 2012;22(4):167–172.

11. Scoppa F, Gallamini M, Belloni G, Messina G. Clinical Stabilometry standardization: Feet position in the static stabilometric assesment of postural stability. *Acta Medica Mediterr*. 2017;33:707.

12. Gurgel RK, Jackler RK, Dobie RA, Popelka GR. A new standardized format for reporting hearing outcome in clinical trials. *Otolaryngol Head Neck Surg*. 2012;147(5):803-807.

13. World Health Organization. Grades of hearing impairment. https://www.who.int/pbd/deafness/hearing_impairment_grades/en/. January 1, 2019.

14. Shepard NT, Jacobson GP. The caloric irrigation test. *Handb Clin Neurol*. 2016;137:119-131.

15. Bronstein AM. Multisensory integration in balance control. *Handb Clin Neurol*. 2016;137:57-66.

16. Nardone A, Schieppati M. The role of instrumental assessment of balance in clinical decision making. *Eur J Phys Rehabil Med*. 2010;46(2):221-237.

17. Bergin PS, Bronstein AM, Murray NMF, Sancovic S, Zeppenfeld DK. Body sway and vibration perception thresholds in normal aging and in patients with polyneuropathy. *J Neurol Neurosurg Psychiatry*. 1995;58(3):335-340.

18. Viljanen A, Kaprio J, Pyykkö I, et al. Hearing as a predictor of falls and postural balance in older female twins. *J Gerontol A Biol Sci Med Sci*. 2009;64(2):312-317.

19. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: A review of an emerging area of research. *Gait Posture*. 2002;16(1):1-14.

20. Maheu M, Sharp A, Landry SP, Champoux F. Sensory reweighting after loss of auditory cues in healthy adults. *Gait Posture*. 2017;53:151-154.

21. Zhong X, Yost WA. Relationship between postural stability and spatial hearing. *J Am Acad Audiol*.

2013;24(9):782-788.

22. Stevens MN, Barbour DL, Gronski MP, Hullar TE. Auditory contributions to maintaining balance. *J Vestib Res*. 2016;26(5-6):433-438.

23. Rumalla K, Karim AM, Hullar TE. The effect of hearing aids on postural stability. *Laryngoscope*. 2015;125(3):720-723.

24. Weaver TS, Shayman CS, Hullar TE. The effect of hearing aids and cochlear implants on balance during gait. *Otol Neurotol*. 2017;38(9):1327-1332.

25. Negahban H, Bavarsad Cheshmeh ali M, Nassadj G. Effect of hearing aids on static balance function in elderly with hearing loss. *Gait Posture*. 2017;58(7):126-129.

26. Kanegaonkar RG, Amin K, Clarke M. The contribution of hearing to normal balance. *J Laryngol Otol*. 2012;126(10):984-988.

27. Besser J, Stropahl M, Urry E, Launer S. Comorbidities of hearing loss and the implications of multimorbidity for audiological care. *Hear Res*. 2018;369:3-14.

28. Sheffield AM, Smith RJH. The epidemiology of deafness. *Cold Spring Harb Perspect Med*. September 2018:a033258.

29. Gallego A, Juan M, Espinosa M, Antonio J, Escamez L. Genetic contribution to vestibular diseases. *J Neurol*. 2018;265(s1):29-34.

30. Yetişer S, İnce D. Caloric Analysis of patients with benign paroxysmal positional vertigo. *J Int Adv Otol*. 2017;13(3):390-393.

31. Strupp M, Kim J, 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.

32. Ward BK, Agrawal Y, Hoffman HJ, Carey JP, Della Santina CC. Prevalence and impact of bilateral vestibular hypofunction: Results from the 2008 US national health interview survey. *JAMA Otolaryngol - Head Neck Surg*. 2013;139(8):803-810.

33. Guirguis-Blake JM, Michael YL, Perdue LA, Coppola EL, Beil TL. Interventions to prevent falls in older adults: Updated evidence report and systematic review for the US Preventive Services Task Force. *JAMA - J Am Med Assoc*. 2018;319(16):1705-1716.

Tables

Table 1

Age, hearing and postural balance by diagnosis in 1075 patients referred for dizziness of suspected vestibular origin

Diagnosis[a]	n	%	Mean age	Hearing threshold (PTA)		Platform posturography		
				Best ear	Worst ear	EO	EC	RQ
Vestibular neuritis	101	9.4	51.5 (15.0)	15.0 (11.0)	21.4 (18.6)	712.4 (472.8)	1214.1 (884.2)	1.70 (0.69)
BPPV	112	10.4	51.8 (14.2)	15.7 (13.1)	20.3 (18.1)	624.6 (304.6)	1024.0 (732.5)	1.65 (0.61)
Ménière's disease	155	14.4	51.5 (14.5)	21.2 (15.5)	41.8 (23.2)	596.3 (392.5)	997.8 (806.5)	1.63 (0.62)
Vestibular schwannoma	71	6.6	53.8 (12,1)	22.0 (15.5)	54.1 (27.3)	606.2 (296.6)	1089.9 (782.8)	1.81 (0.99)
Other inner or middle ear disease	42	3.9	46.4 (15.0)	25.6 (19.3)	44.6 (27.3)	548.2 (292.3)	862.3 (534.7)	1.55 (0.44)
Cerebrovascular	68	6.3	64.7 (13.5)	24.1 (14.7)	30.9 (21.0)	853.9 (504.2)	1656.8 (1502.4)	1.88 (1.07)
Other non-vestibular disease	353	32.8	46.6 (16.1)	14.3 (13.5)	19.2 (17.1)	654.1 (464.1)	1084.0 (898.2)	1.67 (0.82)
Unknown or missing diagnosis	173	16.1	51.6 (16.2)	18.0 (15.9)	24.7 (20.5)	656.1 (504.9)	1089.2 (877.2)	1.69 (0.67)
ANOVA p-value[b]:				**<0.001**	**<0.001**	**0.0003**	**0.0002**	0.5657

Abbreviations: PTA=Pure Tone Average, EO= Path length with eyes open, EC= Path length with eyes closed, RQ=Rombergs quotient of path length (eyes closed/eyes open),

[a] Vestibular diagnosis are considered the main diagnosis, only one diagnosis is possible

[b] For EO, EC and RQ, ANOVA are performed on log-transformed variables

Standard deviations are presented in parenthesis.

Table 2

The effect of hearing loss on postural balance. Analyzed by regression analysis for the logarithm of path length with eyes closed in 1075 patients with dizziness

	Crude		Adjusted analysis with best ear		Adjusted analysis with worst ear	
	Coeff[a]. (95% CI)	p-value	Coeff[a]. (95% CI)	p-value	Coeff[a]. (95% CI)	p-value
Sex (female)	-0.123 (-0.203; -0.042)	**0.003**	-0.104 (-0.182; -0.026)	**0.009**	-0.110 (-0.189; -0.031)	**0.006**
Age (years)	0.009 (0.007; 0.012)	**<0.001**	0.007 (0.004; 0.009)	**<0.001**	0.008 (0.006; 0.011)	**<0.001**
PTA best ear	0.010 (0.007; 0.012)	**<0.001**	0.006 (0.003; 0.009)	**<0.001**		
PTA worst ear	0.004 (0.003; 0.006)	**<0.001**			0.002 (0.000; 0.004)	**0.037**

Coeff. represents coefficients from regression analysis for the natural logarithm of path length with eyes closed.

[b] Asymmetric vestibular function is defined as asymmetry on caloric irrigation ≥ 25% on caloric testing according to Jongkees' formula.

Table 3

The effect of comorbidities on postural balance. Analyzed by regression analysis for the logarithm of path length with eyes closed in 1075 patients with dizziness

	Crude		Adjusted for age, sex, hearing and comorbidities	
	Coeff[a]. (95% CI)	p-value	Coeff[a]. (95% CI)	p-value
Sex (female)	-0.123 (-0.203;-0.042)	**0.003**	-0.104 (-0.182;-0.025)	**0.010**
Age (year)	0.009 (-0.007;0.012)	**<0.001**	0.006 (0.003;0.009)	**<0.001**
PTA best ear	0.010 (0.007;0.012)	**<0.001**	0.006 (0.003;0.009)	**<0.001**
Diabetes mellitus	0.193 (-0.068;0.454)	0.146	0.060 (-0.198;0.319)	0.646
Heart disease	0.179 (0.005;0.352)	**0.044**	-0.001 (-0.179;0.178)	0.995
Former stroke/TIA	0.256 (-0.008;0.519)	0.057	0.051 (-0.218;0.320)	0.711
Hypertension	0.184 (0.066;0.302)	**0.002**	0.076 (-0.048;0.199)	0.231

Abbreviations: PTA=Pure Tone Average, TIA= Transient Ischemic Attack

[a] Coeff. represents coefficients from regression analysis for the natural logarithm of path length with eyes closed.

Table 4

The effect of hearing loss on postural balance adjusted for dizziness diagnoses. Analyzed by regression analysis for the logarithm of path length with eyes closed in 1075 patients with dizziness.

	Crude		Adjusted analysis for best ear		Adjusted analysis for worst ear	
	Coeff[a] (95% CI)	p-value	Coeff[a] (95% CI)	p-value	Coeff[a] (95% CI)	p-value
Sex (female)	-0.123 (-0,204; -0.043)	**0.003**	-0.103 (-0.182; -0.025)	**0.010**	-0.107 (-0.185; -0.028)	**0.008**
Age (years)	0.009 (0.007; 0.012)	**<0.001**	0.005 (0.002; 0.008)	**<0.001**	0.007 (0.004; 0.009)	**<0.001**
PTA worst ear	0.004 (0.003 ;0.006)	**<0.001**			0.004 (0.002; 0.006)	**<0.001**
PTA best ear	0.010 (0.007; 0.012)	**<0.001**	0.007 (0.004; 0.010)	**<0.001**		
<u>Diagnoses*</u>						
-BPPV	ref		ref		ref	
-Vestibular neuritis	0.110 (0.067; 0.287)	0.222	0.098 (-0.073; 0.270)	0.260	0.089 (0.083; 0.261)	0.310
-Ménière's disease	-0.095 (-0.255; 0.064)	0.241	-0.151 (-0.307; 0.005)	0.058	-0.196 (-0.358; -0.035)	**0.017**
-Vestibular schwannoma	0.036 (-0.159; 0.231)	0.718	-0.048 (-0.238; 0.143)	0.624	-0.139 (-0.341; 0.062)	0.175
-Other inner or middle ear disease	-0.184 (-0.417; 0.049)	0.122	-0.242 (-0.471; -0.013)	**0.038**	-0.261 (-0.494; -0.027)	**0.029**
-Cerebrovascular	0.339	**<0.001**	0.196	**0.048**	0.198	**0.047**

	(0.141; 0.536)		(-0.001; 0.391)		(0.002; 0.393)	
-Other non-vestibular	-0.015 (-0.154; 0.125)	0.834	0.008 (-0.128; 0.144)	0.909	0.009 (-0.128; 0.146)	0.897
-Unknown or missing diagnosis	-0.047 (-0.203; 0.109)	0.553	-0.070 (-0.221; 0.081)	0.363	-0.071 (-0.222; 0.081)	0.361

* Vestibular diagnosis are considered the main diagnosis and only one diagnosis is possible

[a] Coeff. represents coefficients from regression analysis for the natural logarithm of path length with eyes closed

Abbreviations: PTA=Pure Tone Average, BPPV= Benign Paroxysmal Positional Vertigo

Table 5:
The effect of hearing loss on postural balance in different age-groups. Analyzed by regression analysis for the logarithm of path length with eyes closed adjusted for sex in 1075 patients with dizziness

	1.Quantile (9-39 years)		2. Quantile (39-50 years)		3.Quantile (50-62 years)		4. Quantile (62-86 years)	
	Coeff[a]. (95% CI)	p-value	Coeff[a]. (95% CI)	p-value	Coeff[a]. (95% CI)	p-value	Coeff[a]. (95% CI)	p-value
Sex (female)	-0.946 (-0.245; 0.055)	0.215	-0.098 (-0.258; 0.061)	0.226	-0.008 (-0.158; 0.141)	0.912	-0.225 (-0.402; -0.047)	**0.013**
PTA best ear	0.007 (0.001; 0.013)	**0.014**	0.005 (-0.002; 0.012)	0.160	0.006 (0.000; 0.012)	**0.030**	0.006 (-0.000; 0.012)	0.061

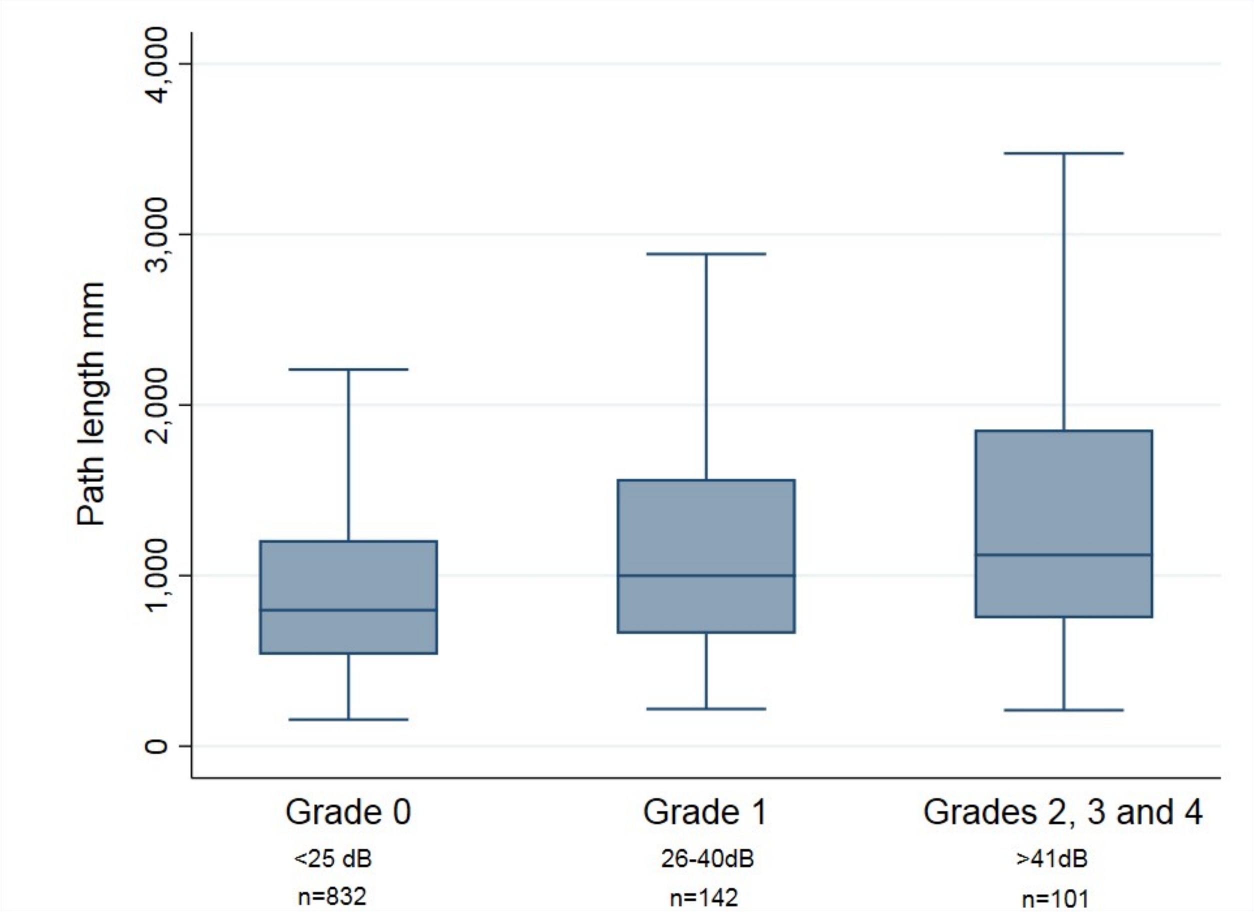
Abbreviations: PTA=Pure Tone Average

[a] Coeff. represents coefficients from regression analysis for the natural logarithm of path length with eyes closed

Figure legends

Figure 1

Path length with eyes closed for 1075 dizzy patients by grades of hearing impairment



Path length of quiet standing with eyes closed by WHO-grades of hearing impairment. Boxes display median and interquartile range. The length of the whiskers are 1.5 times the interquartile range, no outliers plotted.