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Walking and balance in older adults with age-related hearing loss: A cross-sectional study of cases and matched controls

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ABSTRACT

Background: Hearing loss (HL) is prevalent in older individuals. It is suggested that there is an association between age-related HL, walking and balance, leading to poorer function and increased risk of falls in older individuals.
Research question: Is HL associated with physical performance, gait variability, and postural sway in older adults, and will additional dizziness moderate the effect of HL on balance?
Methods: In this cross-sectional study we examined 100 older individuals (age ≥70 years, 60 % females), divided in two groups, with or without age-related HL. Physical function and balance were evaluated by the Short Physical Performance Battery (SPPB), postural sway measured on a force platform (posturography), and balance in walking (gait variability) measured with a body-worn sensor. Multiple linear regression was used to examine the relationships between the variables, with physical function and balance as outcomes and HL as a dichotomous exposure (>30 dB). For all analyses, we further tested if associations were modified by self-reported dizziness.
Results: Multiple regression analysis with HL, age, sex, education, diabetes, and cardiovascular disease revealed a significant association between reduced SPPB and HL. Multiple linear regression analysis also showed that HL was associated with increased postural sway on firm surface with eyes open and closed after adjusting for age, sex, education, diabetes, and cardiovascular disease. There was significant association between HL and increased gait variability during dual task walking in all directions after adjusting for age, sex, education, diabetes, and cardiovascular disease. Further, we found that the association between HL and SPPB was significantly stronger in those with dizziness compared with those without dizziness. Dizziness also modified the association of HL with the other SPPB sub-scores but not for the other outcomes of postural sway or gait variability.
Significance: In this study, age-related HL was associated with worse physical performance as measured by SPPB, postural sway, and gait variability. This relationship illustrates the importance of assessing physical performance in people with HL to prevent risk of falls and disability.

1. Introduction

Hearing loss (HL) is one of the most prevalent conditions affecting older individuals. It is estimated that about 40 % of those aged 65 and older, and 70 %-90 % of those over 85 have HL [1,2]. As the proportion of older individuals increase, HL has emerged as a pressing public health concern for individuals and imposing a substantial economic burden on society [2,3]. For older individuals, HL has profound consequences, including an increased risk for mental health disorders [3,4], frailty [5], diminished health-related quality of life [6], and social isolation [7]. In a

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recent report, HL is identified as the most significant modifiable mid-life risk factor for dementia, surpassing alcohol use and hypertension [8]. Investigation of possible HL is recommended in the global falls' prevention guidelines from 2022 [9].

Several studies have explored the association between HL and physical functioning in older adults. Lin et al. [10] conducted a systematic review revealing associations between HL and mobility limitations, activity limitations, and participation restrictions. Similarly, Joo et al. [11] identified HL as being associated with reduced mobility and increased risk of injurious falls. Additionally, HL has been linked to reduced life-space mobility [12], to lower limb physical performance and difficulties in activities of daily living [13]. Although many of these studies relied on self-reported HL, which may be unspecific and inaccurate, others have utilized audiometry to confirm associations between HL and physical functioning [14,15]. Systematic reviews further underscore associations between HL and various balance and walking measures [16,17]. Clinical measurement methods such as the Short Physical Performance Battery (SPPB) are very useful for clinical practice [18]. Using devices such as force platforms for measuring center of pressure movements and body-worn sensors for measuring gait variability can give a more nuanced and detailed picture than commonly used clinical tests [19,20]. By using such methods, small movements throughout the gait cycle, that are difficult to see with the naked eye, can be captured in high resolution. Consequently, small movement deviations that can be clinically meaningful can be captured [21].

As dizziness is one of the most prevalent symptoms in older individuals and is also a strong predictor for recurrent falls [22], one could question if dizziness may have an impact on the association between HL and balance. Dizziness is a core symptom in vestibular disorders [23] and Maheu et al. [24] found that hearing aids reduced the risk of falls among individuals with concomitant HL and vestibular deficits. The researchers proposed that the importance of auditory information is heightened when there is a concurrent loss of vestibular function. The same effect was not found in individuals with HL without concurrent dizziness. In contrast, Huang et al. [25] reported that HL was not associated with falls in older adults with dizziness, independent of the cause of dizziness. The contrasting findings suggest that further research is needed.

Previous research indicates an association between HL, gait, and balance. To our knowledge, there are no studies investigating balance in standing and walking in one study using both clinical and instrumented tests in the same sample of older adults. The aim of this study was to investigate the association between HL and physical performance (SPPB), postural sway (posturography), and gait variability (body-worn sensor) under normal and a dual task condition in a group of older adults with age-related HL (>30 dB). Measuring physical performance with a combination of instruments like a SPPB, force platform and accelerometer provides a comprehensive, accurate, and reliable assessment of various aspects of physical function. This approach offers detailed insights, informs targeted interventions, and enhances the ability to identify and address specific physical performance issues [26]. Another aim was to examine if self-reported dizziness could be a moderating factor in the association between HL and balance. For comparison, a group of older individuals with normal hearing (≤30 dB) was recruited and matched in terms of sex and age.

2. Methods

This is a cross-sectional study comparing older individuals with and without HL. The study was conducted at SimArena movement lab at Western Norway University of Applied Sciences (HVL) in Bergen [27], between September 2020 and June 2021. Different recruitment sources were used for participant recruitment. General practitioners from the Norwegian Primary Care Research Network distributed project information to eligible patients [28]. The Norwegian Association of the Hearing Impaired (HLF) distributed information through their newsletter. Audiologists at the Hearing Center at Haukeland University Hospital distributed information to patients they considered suitable. Project information was also distributed to retired staff members at HVL to recruit participants without HL, and this group further extended the invitation to family and friends with HL.

People eligible for participation in the HL group had to be over 70 years of age, have age-related HL (>30 dB),and be users of hearing aids, while participants in the normal hearing group (≤30 dB), had otherwise the same inclusion criteria. Exclusion criteria for both groups were previous ear surgery, neurological disease such as Parkinson's or stroke, have medical conditions that could significantly influence gait and balance such as head or ear injury, or severe osteoarthritis. Furthermore, persons with HL not attributed to the aging process were also excluded from the study. Due to difficulties with recruitment of older individuals during the pandemic, we did not manage to include more than 50 individuals with and 50 without HL within the project period.

2.1. Ethics

The study adhered to the criteria and principles in the Declaration of Helsinki and was approved by the Regional Committee for Medical Research Ethics of South-East Norway (REK Sør-Øst D 33195) as well as the Norwegian Centre of Research Data (NSD 167090). The study was carried out in accordance with the STROBE checklist for cross-sectional studies [29] and registered on Clinical Trials.gov (NCT04283279).

2.2. Procedures and data collection

Eligible individuals provided oral and written, informed consent. Initial contact with potential participants was established by phone or email. Participants then attended the lab for audiometry, questionnaires and physical tests. Participants with HL used hearing aids during testing. The first author (SK), who is an experienced audiologist and a qualified physiotherapist, conducted all the tests.

3. Measurements

3.1. Demographic and epidemiological data collection

Participants completed a questionnaire with date of birth, sex, marital status, education attainment, and the presence of specific medical conditions such as diabetes, cardiovascular diseases, nervous system diseases, ear-related ailments, and dizziness. Questions concerning dizziness, diabetes, and cardiovascular diseases were dichotomous (yes / no).

4. Main outcome

4.1. Physical performance

Physical performance was measured by the Short Physical Performance Battery (SPPB), developed to measure the physical capability and lower extremity physical function status in older individuals [30]. SPPB consists of three timed tasks: standing balance, walking, and chair rise. Standing balance is evaluated in three positions: 1) standing with feet together, 2) semi tandem, and 3) full tandem standing. Each position is held for 10 seconds [31]. Walking (gait speed) was measured as the time in seconds to complete a 4-meter walk at preferred pace. Timing starts with the command "ready – begin" and ends after crossing the marked line 4 m away. Two trials are performed, and the best (fastest) time is recorded [32]. In the chair rise test, the participant is asked to get up from a straight-back standard chair with arms folded across their chest. If the initial chair rise is successfully completed, the participant is asked to repeat the exercise five times as quickly as possible, and time in seconds is recorded [31]. The participant can obtain between 0 and 4 points for each task, thus the total score can vary from 0 to 12. Higher scores are indicative of better function; 0–6 is considered a low score, 7–9 a middle score, and 10–12 a high score [31]. A score lower than 10 is predictive of all-cause mortality [32]. SPPB has demonstrated predictive validity, criterion validity, test-retest reliability and can be used to evaluate change after intervention [33–35].

4.2. Postural sway

Postural sway was measured during quiet standing using a force platform (BTG4, HUR health) [36]. The main parameter for postural sway was trace length (in millimeters) of the center of pressure (COP) while standing quietly for 30 seconds. The participants were asked to stand on the platform with their arms crossed and with their heels two cm apart, under four conditions; firm surface with eyes open (EO firm) and closed (EC firm), and soft surface with eyes open (EO foam) and closed (EC foam). The soft surface was a 6 cm thick Airex foam pad [37]. Validity and reliability of posturography has been found to be acceptable [36,38].

4.3. Walking performance (balance)

Stride variability (gait variability) was included as a measure of walking balance [39]. Gait variability was recorded with a single three-axis Xsens accelerometer (MTx, Xsens Technologies B.V., Enschede). The accelerometer was attached in the lower back with an elastic band. The signals from the accelerometer were wirelessly sent to the computer via Bluetooth. The data was processed by a MATLAB-based application (TRASK). Gait variability in the anteroposterior (AP), vertical (V) and mediolateral (ML) directions was estimated using an autocorrelation procedure [40,41]. Considering gait variability in the AP, V, and ML directions provides unique insights into different aspects of gait and balance [39]. These measures helped to assess the stability, smoothness, and coordination of walking patterns, which might be crucial for understanding mobility, fall risk, and other health-related outcomes [40,41]. This approach has applications in clinical assessment, rehabilitation, fall risk evaluation, and understanding the impact of cognitive load on gait performance. AP direction measures variability in forward and backward motion during walking. V in the vertical direction reflects the degree of bounce or oscillation during walking. ML direction captures variability in side-to-side motion during walking. Autocorrelation was used in a study, that each direction (AP, V, and ML) was analyzed separately (one-dimensional data), focusing on the regularity and repetition of strides over time [41]. Low autocorrelation coefficients, tending towards 0.0 indicate variable and unstable gait, high autocorrelation coefficients tending towards 1.0 indicate a stable gait pattern with strides that resemble one another. We refer to the stride-to-stride variations calculated by autocorrelation as “gait variability”, while earlier authors have referred to this as “gait regularity” [41], which is the technically correct term. However, due do widespread use of the term “gait variability” in the research literature, we employed this term. Gait analysis using sensors is pointed to as valuable in diagnosis and treatment of for example neurodegenerative disorders [42]. Gait parameters derived from trunk accelerometry have been found to have good test-retest reliability (ICCs 0.77–0.96) [43]. In our study, the participants were asked to walk twice along a 6-meter walkway on the marked floor with “start” and “stop” lines. The first trial was to walk at preferred speed. In the second trial, the participants were asked to walk at preferred speed, counting down from 100 every three numbers (i.e. 100, 97, 94, 91, etc.). This latter dual task-condition was added to make the test more demanding. As suggested by Carpenter and Campos [44] people with HL use extra attentional resources to compensate for reduced auditory input. Hence, by adding counting to walking, we assumed that gait impairments would be more pronounced.

5. Exposure

5.1. Hearing threshold

Hearing was examined without hearing aids by a portable screening audiometer for manual pure tone audiometry (MADSEN Micromate 304 with TDH-39 supra-aural audiometric headphones). To examine hearing threshold, air-conduction pure-tone audiometry (PTA) at four frequencies from 0.5, 1, 2, and 3 kHz, measured in dB hearing level / HL was calculated separately on each ear as recommended by the Hearing Committee of the American Academy of Otolaryngology – Head and Neck Surgery [45], and the results from the better ear was used as this has been shown to have better correlation with physical performance [19]. The assessment was done in a quiet environment. Sensitivity and specificity of audiometry has been found to be acceptable [46].

6. Co-variates

To assess the independent role of HL on balance/physical performance, the following variables (covariates) were collected and adjusted for in regression analyses: age, sex, education, diabetes, and cardiovascular disease. The covariates were selected based on a directed acyclic graph (DAG), using the online software DAGitty [47]. The program was designed to construct, edit, and examine causal diagrams to minimize bias in empirical studies in epidemiology and other disciplines [47]. (See Fig. 1s in Supplementary materials).

7. Other measurements

7.1. The Dizziness Handicap Inventory (DHI-N)

The Dizziness Handicap Inventory (DHI) is a questionnaire designed to evaluate the impact of dizziness on a person’s daily life [48]. DHI contains 25 questions, with ratings "0" for no, "2" for sometimes, and "4" for yes. Giving a total score of 0–100 with higher scores indicating higher perception of disability. DHI has been translated and validated into Norwegian, demonstrating satisfactory measurement properties [49]. Cut-off, i.e. 29 DHI points discriminates between participants with and without disability [49].

7.2. The Trail Making Test (TMT)

Trail Making Test (TMT) A and B are neuropsychological tests examining executive function, visual scanning and working memory [50]. In each test, the participant is asked to draw a line between 24 successive circles, randomly placed on the page. TMT-A (measures psychomotor speed, visual search and attention skills) uses only numbers, while TMT-B (measures alternation/flexibility, inhibition/interference control, mental tracking, and attentional set-shifting) uses numbers and letters that requires the subject to switch between numbers and letters in order [51]. TMT is evaluated based on the time it takes to complete the test. If an individual is unable to complete the test within 5 minutes, the test is discontinued. The average time score on the TMT-A is 29 seconds and the failing (time) score exceeds 78 seconds. For TMT-B, the average time score is 75 seconds, and the failing (time) score is more than 273 seconds [50].

8. Analysis

All analyses were performed using IBM SPSS Statistics 27. Means, standard deviations, frequencies and percentages were used to describe the sample characteristics. HL was defined as having a PTA >30 dB whereas normal hearing was defined as having a PTA ≤ 30 dB. Furthermore, participants were categorized based on their response to a single question concerning dizziness: “yes” or “no”. Multiple linear regression was used to examine the association of HL (exposure) with physical function, gait speed, and balance (outcomes), using normal hearing as the reference category. The outcomes were measured by SPPB total score, SPPB subs-cores, postural sway (EO firm, EC firm, EO foam, EC foam) and gait variability (single task and dual task). The four postural sway variables (EO firm, EC firm, EO foam, EC foam) were not normally distributed, and these variables were log-transformed so that the residuals approached normality, and were expressed as logEOfirm, logECfirm, logEOfoam, logECfoam. All regression analyses were both performed unadjusted and adjusted for the following co-variates: age, sex, education (Model 1), Model 1 + diabetes and cardiovascular diseases (Model 2) as independent categorical variables. For all analyses, we further tested if associations were modified by dizziness. This was done by comparing adjusted models with and without an HL-by-dizziness interaction term, using likelihood ratio tests.

9. Results

The study included 50 participants with HL (PTA >30 dB) and 50 participants with normal hearing (PTA ≤30 dB). The mean age among the participants with HL was 76.2 yrs. (4.8 SD) and 60 % were female. The mean age in the normal hearing group was 76.6 yrs. (4.6 SD) and 66 % were female. Among participants with HL, 19 (38 %) reported to have dizziness and only 4 (8 %) in the normal hearing group. Most of the participants with HL (82 %) and normal hearing (82 %) were university educated. Five (10 %) participants with HL had diabetes and 2 (4 %) cardiovascular diseases. One (2 %) person with normal hearing reported diabetes and 3 (6 %) cardiovascular diseases. Participants with HL and dizziness had higher scores on DHI, but below the 29 point cut-off value. There were no differences in the cognitive tests (Trail making test A and B) between participants with and without HL (Table 1). All participants completed the TMT tasks according to the guidelines and there was no need to discontinue the TMT tests.

Figs. 1–3 shows a graphical presentation of the test results for the three balance tests: the SPPB (Fig. 1), postural sway (posturography) (Fig. 2), and gait variability (Fig. 3). The results for the SPPB total score and sub-scores illustrates that performance in the normal hearing group was better compared to the HL group, and that those with HL reporting additional dizziness, generally performed worse than persons without dizziness in the group with HL (Fig. 1). Posturography shows a more varying result, but with HL patients generally having higher postural sway. For the gait variability tests (Fig. 3), the most visible difference appeared in the dual-task condition, with the HL group performing worse compared to the group of individuals without HL. Please see Table 2s in supplementary materials for details.

Tables 2–4 present the association between HL as the exposure and SPPB total score and sub-scores, postural sway, and gait variability as outcomes. Multiple linear regression analysis (Model 2) showed that HL was significantly associated with worse SPPB total score (b = −2.151 (95 %CI: −2.932 to −1.370) p<0.001), and its sub-scores standing balance (b = −0.939 (95 %CI: −1.287 to −0.591) p<0.001), gait speed (b= −0.754 (95 %CI: −1.053 to −0.455) p<0.001), and chair stand (b = −0.458 (95 %CI: −0.737 to −0.180) p=0.002) (Table 2).

Multiple linear regression analysis (Model 2) also showed that HL was significantly associated with postural sway on firm surface with eyes open (b = 0.317 (95 %CI: 0.145–0.488) p<0.001) and closed (b = 0.274 (95 %CI: 0.042–0.507) p=0.021) as well as with postural sway on foam surface with eyes closed (b = (95 %CI: 0.295 (0.020–0.570) p=0.036) (Table 3). We also found an association between HL and postural sway on foam surface with eyes open, but the association did not reach statistical significance on the 0.05 level.

There was no significant association between HL and gait variability during unconstrained gait speed. However, during dual task gait speed, there were significant associations between HL and gait variability, in all directions. This association remained after adjusting for covariates (Model 2) (b = −0.164 (95 %CI:-0.279 to −0.049) p = 0.006).

10. Interaction analyses

The associations between HL and SPPB total score and all its sub-scores were stronger in those with dizziness compared with those without dizziness in the group with HL (Supplementary materials Table 4s). For SPSS total score, the coefficient (b) for HL was −4.44 (95 %CI: −6.20 to −2.69, p<0.001) in those who reported dizziness and −0.831 (95 %CI: −1.56 to −0.110, p=0.025) in those with HL who did not report dizziness (p for interaction <0.001). We found no other no interaction effect for dizziness in the association analysis for postural sway and gait variability (Supplementary materials Table 5s, 6 s).

Table 1
Distribution of demographics and comorbidities in persons with normal hearing (N=50), hearing loss without self-reported dizziness (N=31), and hearing loss with self-reported dizziness (N=19).

	Normal hearing N=50	Hearing loss		
		Hearing loss N=50	Hearing loss without dizziness N=31	Hearing loss with dizziness N=19
Age, mean (SD)	76.6 (4.6)	76.2 (4.8)	75.5 (4.9)	77.4 (4.7)
Sex, N (%)				
men	17 (34)	20 (40)	13 (41.9)	7 (36.8)
women	33 (66)	30 (60)	18 (58.1)	12 (63.2)
Education, N (%)				
high school	9 (18)	9 (18)	4 (12.9)	5 (26.3)
university	41 (82)	41 (82)	27 (87.1)	14 (73.7)
Diabetes, N (%)				
no	49 (98)	45 (90)	29 (93.5)	16 (84.2)
yes	1 (2)	5 (10)	2 (6.5)	3 (15.8)
Cardiovascular diseases, N (%)				
no	47 (94)	48 (96)	31 (100)	17 (89.5)
yes	3 (6)	2 (4)	0 (0.0)	2 (10.5)
Dizziness, N (%)				
no	46 (92)	31 (62)	31 (62)	———
yes	4 (8)	19 (38)	———	19 (38)
PTA, mean (SD)	3.0 (3.1)[a]	51.1 (11.2)	51.1 (12.5)	51.2 (9.1)
TMT-A, mean (SD)	46.3 (19.1)	47.7 (16.7)	48.5 (17.5)	46.4 (15.7)
TMT-B, mean (SD)	115.7 (44.3)	109.5 (50.6)	110.0 (57.2)	108.5 (39.1)
DHI-N total score, mean (SD)	2.0 (6.1)	8.1 (17.2)	2.1 (3.6)	18.0 (24.9)

Abbreviations: PTA = Pure Tone Audiometry, measured in dB. TMT-A = Trail Making Test A, measured in seconds. TMT-B = Trail Making Test B, measured in seconds. DHI-N total score = Dizziness Handicap Inventory – Norwegian version, total score 0–100.
[a] Missing data of PTA N=14.

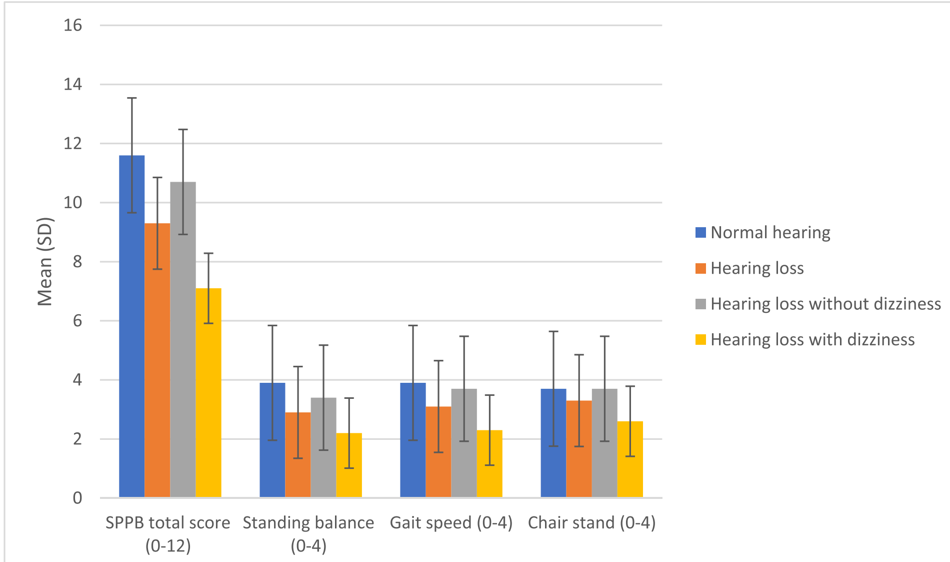

Fig. 1. Distribution of physical performance (SPPB total score, standing balance, gait speed and chair stand) in persons with normal hearing (N=50), hearing loss (N=50), hearing loss without self-reported dizziness (N=31), and hearing loss with self-reported dizziness (N=19). Error bars in SD.

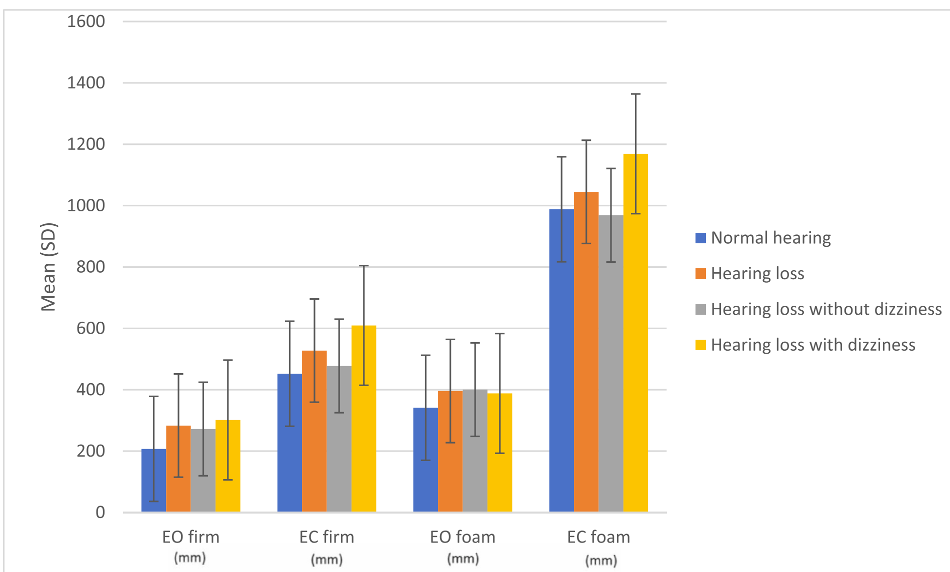

Fig. 2. Distribution of postural sway on a firm and foam surface with eyes open and closed in persons with normal hearing (N=50), hearing loss (N=50), hearing loss without self-reported dizziness (N=31), and hearing loss with self-reported dizziness (N=19). Postural sway is measured as sway path in millimeters (mm). Error bars in SD.

11. Discussion

In this cross-sectional study, we examined if HL was independently associated with SPPB, postural sway, and gait variability in older individuals with and without HL. To our knowledge, few studies have assessed physical performance, balance in standing (posturography), and in walking in the same sample of individuals. Measuring physical performance using multiple instruments, such as SPPB, force platform and accelerometer, is important because it provides a comprehensive and multidimensional assessment of physical function [38,52] which is essential for everyday activities. Each tool measures a different aspect of physical performance. The SPPB evaluates lower-body strength, balance, and gait speed [32], the force platform assesses balance and weight distribution [38], and the accelerometer captures movement dynamics [41]. By combining these instruments, a broader understanding of physical function is gained regarding balance and mobility which cannot be fully captured with a single instrument [38]. If one instrument indicates an anomaly, other tools can confirm or refute it. This reduces the likelihood of errors or misinterpretations, leading to more reliable results. The instruments can be used in both clinical and research settings, providing practical applications for assessing physical performance in a variety of contexts. They are also useful for tracking progress over time, allowing ongoing monitoring and adjustment of treatment plans. Combining different measurement instruments allows for validation and correlation of results. If results from one instrument correlate with those from another, it strengthens the validity of the findings [37]. This is especially important in research, where robust data is crucial.

The main findings in the current study were the significant negative associations between HL and SPPB total score, which implies worse

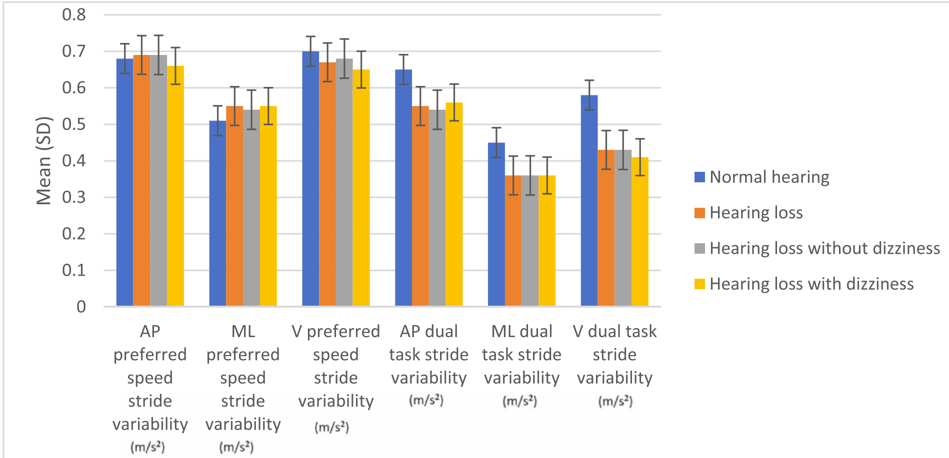

Fig. 3. Distribution of walking balance (single and dual task) in persons with normal hearing (N=49), hearing loss (N=47), hearing loss without self-reported dizziness (N=30), and hearing loss with self-reported dizziness (N=17). Walking balance is measured as gait variability in meters per second squared (m/s^2). Error bars in SD.

Table 2
Association between hearing loss and physical performance (SPPB) in persons with (N=50) and without HL (N=50).

Outcome	Crude		Model 1		Model 2	
	Coefficient (95 % CI)	P Value	Coefficient (95 % CI)	P Value	Coefficient (95 % CI)	P Value
SPPB total score	−2.260 (−3.055 to −1.465)	<0.001	−2.290 (−3.086 to −1.494)	<0.001	−2.151 (−2.932 to −1.370)	<0.001
Standing Balance	−0.980 (−1.330 to −0.630)	<0.001	−0.993 (−1.346 to −0.641)	<0.001	−0.939 (−1.287 to −0.591)	<0.001
Gait Speed	−0.800 (−1.097 to −0.503)	<0.001	−0.803 (−1.103 to −0.503)	<0.001	−0.754 (−1.053 to −0.455)	<0.001
Chair Stand	−0.480 (−0.761 to −0.199)	0.001	−0.494 (−0.773 to −0.215)	0.001	−0.458 (−0.737 to −0.180)	0.002

Abbreviations: SPPB= Short Physical Performance Battery; Model 1 = Adjusted for age, sex, and education. Model 2 = Adjusted for age, sex, and education, diabetes, and cardiovascular disease. $p < 0.05$

Table 3
Association between hearing loss and postural sway (N=100).

Postural sway	Crude		Model 1		Model 2	
	Coefficient (95 % CI)	P Value	Coefficient (95 % CI)	P Value	Coefficient (95 % CI)	P Value
logEOfirm	0.296 (0.125–0.468)	<0.001	0.300 (0.132–0.469)	<0.001	0.317 (0.145–0.488)	<0.001
logECfirm	0.246 (0.007–0.485)	0.044	0.241 (0.009–0.473)	0.042	0.274 (0.042–0.507)	0.021
logEOfoam	0.126 (−0.055–0.307)	0.169	0.126 (−0.051–0.303)	0.162	0.154 (−0.020–0.327)	0.082
logECfoam	0.258 (−0.014–0.530)	0.063	0.262 (−0.012–0.535)	0.060	0.295 (0.020–0.570)	0.036

Abbreviations: logEOfirm = Postural sway on a firm surface with eyes open. logECfirm = Postural sway on a firm surface with eyes closed. logEOfoam = Postural sway on a soft surface with eyes open. logECfoam = Postural sway on a soft surface with eyes closed. Model 1: adjusted for age, sex, education; Model 2: adjusted for age, sex, education, diabetes and cardiovascular disease, $p < 0.05$

Table 4
Association between hearing loss and walking balance (N=96).

Outcome	Crude		Model 1		Model 2	
	Coefficient (95 % CI)	P Value	Coefficient (95 % CI)	P Value	Coefficient (95 % CI)	P Value
AP	0.006 (−0.047–0.058)	0.832	0.005 (−0.048–0.058)	0.853	0.009 (−0.046–0.063)	0.753
ML	0.037 (−0.024–0.098)	0.233	0.039 (−0.022–0.101)	0.210	0.037 (−0.027–0.100)	0.253
V	−0.031 (−0.096–0.033)	0.340	−0.031 (−0.096–0.035)	0.357	−0.030 (−0.098–0.037)	0.371
AP dual task	−0.097 (−0.179 to −0.014)	0.022	−0.099 (−0.183 to −0.015)	0.022	−0.092 (−0.178 to −0.005)	0.038
ML dual task	−0.083 (−0.159 to −0.008)	0.031	−0.084 (−0.161 to −0.007)	0.034	−0.088 (−0.167 to −0.009)	0.030
V dual task	−0.158 (−0.268 to −0.047)	0.006	−0.162 (−0.274 to −0.050)	0.005	−0.164 (−0.279 to −0.049)	0.006

Abbreviations: AP = anteroposter. ML = mediolateral. V = vertical. Model 1: adjusted for age, sex, education; Model 2: adjusted for age, sex, education, diabetes and cardiovascular disease, $p < 0.05$

physical performance, increased postural sway on firm surface with eyes open and closed after adjusting for age, sex, education, diabetes, cardiovascular disease, and dizziness. There was also a significant association between HL and gait variability during dual task walking across all three directions (A, V and ML) in model 1 and 2 in Table 4.

The finding that HL was associated with lower SPPB total scores, is consistent with our previous findings [15] suggesting that people with HL could face an increased risk of falls [38] as well as all-cause mortality [32]. It is encouraging that a clinical test which is easily performed without specialized equipment may detect balance and walking impairments comparable to findings from instrumented tests. This observation emphasizes the value of SPPB in clinical practice; inform clinical decisions, guide therapy and rehabilitation, and help to identify those at risk for mobility-related complications. The SPPB can facilitate discussions between clinicians and patients about goals of care, mobility expectations, and treatment options. Its ability to provide standardized measures of physical performance makes it a cornerstone in geriatric care and beyond. Analyzing the subtasks of SPPB, showed that the chair rise-test was not significantly associated with HL when adjusted for diabetes and cardiovascular disease. It could be speculated that HL is more closely associated with balance and gait than lower extremity strength.

Our results demonstrated a significant association between HL and increased postural sway on firm surface with eyes open and closed, as well as on foam surface with eyes closed in model 2 (Table 3). This aligns with the findings reported by Berge et al. [19] and the insights from the systematic review conducted by Agmon et al. [16], both suggesting that age-related HL might compromise standing balance during daily activities, potentially elevating the risk of falls. As summarized by Carpenter and Campos [44], there are inconsistencies in the previous literature with respect to whether sound attenuation and/or hearing loss are associated with worse postural outcomes.

The current study also revealed that individuals with HL exhibit greater variability in their gait when performing dual-task gait than individuals with normal hearing. This observation aligns with findings reported by Sakurai et al. [20], who identified an association between HL and increased gait variability among older individuals, which was in turn associated with a higher risk of experiencing a fall. However, it is important to note that the exact nature of the association between HL and gait variability remains unclear. One plausible explanation is that they share a common underlying factor related to information selectivity, involving the interplay between cognitive load and the spatial control of gait, as suggested by Sakurai's and Lau's research [20,53]. Notably, the participants in Lau et al.s' study walked in a virtual environment, which can influence gait in itself [53]. Further investigation in this area is warranted to better understand the relationship between HL and gait variability.

In the interaction analyses, self-reported dizziness showed a significant modification of the association between HL with SPPB total score as well as the three sub-scores of SPPB. This suggests that dizziness may be an important actor to consider. It could be speculated that auditory and vestibular pathology occurs concomitantly, but research on this is limited [54]. Some studies [55,56] have found that older adults with HL have problems discriminating pitch movements in a dark setting, indicating a potential link between HL and poorer vestibular perceptual sensitivity. It is speculative to suggest that this association could explain why participants with self-reported dizziness exhibited worse physical performance (SPPB), as shown in the interaction analysis, as we lack vestibular history and assessment. Further research is required to shed light on these questions. However, self-reported dizziness did not significantly modify the association between HL and gait variability and posturography. The reason behind this is not immediately clear, considering that standing and walking are involved in all three measures. It could be argued that the tasks involving digital devices were more challenging, e.g. standing with eyes closed on foam or counting backwards while walking. Additionally it is worth noting that digital capturing tests provide a more detailed assessment of movement quality, while the SPPB offers a summary score of balance and mobility performance.

Our findings may have limited generalizability due to the selectivity of our sample, influenced by higher education levels, few comorbidities, and pandemic-related recruitment challenges. It is well established that individuals with higher education are healthier compared to those with lower educational attainment [4]. The cross-sectional design prevents establishing causality. We acknowledge that we did not conduct formal vestibular function testing, despite its known associations with postural sway and gait variability. This warrants further investigation, as dizziness may serve as an indicator of vestibular loss, which is a known modulator of the benefit of hearing aids [24]. Furthermore, technical limitations hindered the collection of complete data on PTA from 14 people with normal hearing. To maximize the feasibility of our analyses, we opted to employ recruitment status (hearing impairment and no hearing impairment) as the exposure variable. These limitations should be considered when interpreting our findings and underscore the need for future studies.

In conclusion, group belonging (HL or not HL) was associated with balance and gait outcomes, and self-reported dizziness demonstrated a modifying effect on the association between HL and SPPB. We argue that physical performance assessments belong in evaluation of fall risk, frailty assessments and mobility assessments in individuals with HL, and that dizziness should be considered as an influencing factor in the assessment. We believe that the associations found in our study, using exact and objective measurements of standing and walking balance, are important contributions to a growing body of empirical evidence linking HL to balance problems in the elderly population.

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CRediT authorship contribution statement

Liv Heide Magnussen: Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Formal analysis. **Roy Miodini Nilsen:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis, Data curation. **Stein Helge Glad Nordahl:** Writing – review & editing. **Dara Meldrum:** Writing – review & editing. **Kjersti Thulin Wilhelmsen:** Writing – review & editing, Validation. **Fredrik Kragerud Goplen:** Writing – review & editing, Validation. **Ole Martin Steihaug:** Writing – review & editing. **Bård Bogen:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition. **Jan Erik Berge:** Writing – review & editing, Validation. **Susanne Sørensen Hernes:** Writing – review & editing. **Sylwia Kolasa:** Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Formal analysis.

Declaration of Competing Interest

There was no conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2024.07.301.

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