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Self-reported hearing measures can predict risk of falling and balance problems

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Hanna Putter-Katz[1], Niza Horev[1,2], Erez Yaakobi[3] & Ella Been[1,4]

Abstract

Introduction Falls in the elderly are a major source of injury that can result in disability and hospitalization. Early detection of balance deterioration and the risk of falling is thus crucial to preventive care. Older adults with hearing loss are 2.4 times more likely to experience falls than their normal-hearing peers. This study explored the utility of a self-reported hearing measure (The Amsterdam Inventory for Auditory Disability and Handicap—AIADH) as a predictor of balance problems and the risk of falling.
Methods A sample of 148 individuals (18–90 years) completed two objective hearing tests (Standard Pure-Tone Audiometry and Words-in-Noise), one self-reported hearing inventory—AIADH, one balance test—Timed Up and Go, and the Activity-Specific Balance Confidence Scale that self-reports balance. The analysis included correlation and regression analyses, moderation, sensitivity, and specificity analyses.
Results The findings suggest that AIADH constitutes a good predictor of a decline in balance and an increased risk of falling, which complements objective hearing measures in adults aged forty and over. Prediction accuracy rises with age. The findings also reveal that out of all the AIADH subscales, the detection subscale is the best predictor of balance problems and risk of falling.
Conclusions Thus, using an available self-report hearing inventory can be a useful and potentially cost-effective tool for the early detection of balance problems and hearing deterioration. Health authorities should consider incorporating this type of evaluation as a remote screening tool for large populations at risk.

Plain language summary

As people get older, falls become a major health risk, especially for those with hearing loss, who are more than twice as likely to fall. This study examined whether a self-reported hearing test (AIADH) could predict balance issues and fall risk. A total of 148 individuals (ages 18–90) completed the AIADH and fall risk measures. The results showed that the AIADH is an effective predictor of balance decline, especially in adults over forty. Its accuracy improved with age, and among the AIADH subscales, the “detection” subscale was the strongest predictor of balance issues and fall risk. These findings suggest that a simple, self-reported hearing test could serve as a cost-effective screening tool for detecting balance problems early. Health authorities might consider using it for remote screenings to help prevent falls in at-risk populations.

Falls and fall-related injuries are major sources of mortality, disability, and dysfunction in older people, and constitute an important global public health concern[1–4]. The World Health Organization estimated that globally, more than 680,000 individuals die annually as a result of fall and fall-related injuries. Approximately 172 million falls result in a fracture which can cause short and long-term disabilities[5]. The early detection of balance deterioration and risk of falls is thus crucial. Accurate assessment of fall risk can allow for earlier fall-risk reduction interventions such as physical therapy, home fall prevention fittings, and staged withdrawal from certain medications. Early interventions can reduce the incidence of falls, fall-related costs, fear of falling, and negative effects on quality of life[6]. Clinical fall risk assessment tools often utilize questionnaires and/or functional evaluations of posture, gait, cognition and other risk factors. However, these have several limitations related to the subjective, qualitative nature of their methodologies[6,7]. Nevertheless, the remote monitoring of adults to detect balance deterioration and risk of falls is a key component of modern telemedicine[8] including smartphone applications, smart watches, accelerometer sensors, telehealth video calls or questionnaires[8].

Hearing interacts significantly with balance in adults, and hearing impairment is correlated with the occurrence of falls in older people[9–12]. In recent years, a growing body of evidence has suggested that hearing cues contribute to balance. Studies show that auditory information can be integrated with vestibular, somatosensory, and visual signals to improve balance, orientation, and gait[11]. Older adults with a hearing impairment have a

[1]Department of Communication Sciences and Disorders, Faculty of Health Professions, Ono Academic College, Kiryat Ono, Israel. [2]Speech and Hearing Unit, ENT Department, Tel Aviv Sourasky Medical Center, Tel Aviv, Israel. [3]Faculty of Business Administration, Ono Academic College, Kiryat Ono, Israel. [4]Department of Sports Therapy, Faculty of Health Professions, Ono Academic College, Kiryat Ono, Israel. e-mail: hputter@ono.ac.il

1.49 fold greater risk of falling[13,14]. Nevertheless, research has indicated that treating hearing impairments can improve balance[15–17], which suggests that the assessment of hearing impairments should be a targeted aspect of fall prevention[10,14,18,19]. To the best of our knowledge, no fall prevention programs/policies detect or prioritize hearing loss as a risk factor. In the literature, both objective and subjective measures have been used to study the interaction between hearing loss, balance and risk of falling[11–17].

Over 1.5 billion people live with some degree of hearing loss worldwide. Its prevalence will almost double by 2050 due to increased life expectancy[20]. Although the prevalence of hearing loss is the highest in people aged 65 years and older, a substantial number of adults under the age of 65 also experience hearing difficulties. Because of differences in lifestyle between these younger adults and adults of retirement age, the impact of hearing loss may not be the same[14]. Unfortunately, only 20% of all individuals who might benefit from treatment actually seek help. Most tend to delay treatment until they experience communication difficulties even in the best of listening situations. On average, hearing aid users wait over 10 years after their initial diagnosis to be fitted with their first set of hearing aids[21].

In rehabilitative audiology, the key focus is on the restoration of audibility. Hearing evaluation tools (e.g. pure-tone thresholds) enable the identification of the magnitude of hearing loss, but they do not reflect the deleterious impact of hearing loss on daily life. In contrast to medical models, the ecological rehabilitation model aims to enhance not only sensory input but also communicative interactions within specific environments and internal variables[22]. Patient-reported outcome measures (PROMS), inventories, and/or questionnaires enable patients to share their views on how their condition affects their daily lives, separately from the analysis of test results by a professional clinician. PROMS are complementary to objective hearing measurements (PTA) to evaluate hearing difficulties, and the changes in hearing throughout rehabilitation. Studies have shown that self-reported hearing problems are the most important factor influencing help-seeking, hearing aid uptake, use, and satisfaction[23]. One of the most frequently administered self-reported hearing questionnaires is the Amsterdam Inventory for Auditory Disability and Handicap (AIADH)[24–26], which is widely used in a variety of clinical settings and research. AIADH questions (30) describe a series of everyday hearing scenarios to detect hearing difficulties. Participants are asked to scale how they perceive their hearing ability in each scenario. This easy-to-use and cost-effective self-reported, internet-based screening tool can help reach out to people in the community and enhance early diagnosis and interventions for balance and hearing deterioration. Despite its potential, AIADH is only administered as a screening tool for hearing loss but not for balance deterioration, although its optional use as a predictor of fall risk was recently recommended by van Wier et al. [12].

This cross-sectional study was designed to evaluate AIADH as a predictor of balance problems and risk of falling. Results demonstrate that AIADH serves as a good predictor of balance deterioration and increased falling risk in adults forty and older, complementing objective hearing assessments. Its predictive accuracy improves with advancing age. Among all AIADH subscales, the detection subscale emerged as the most reliable predictor of balance difficulties and fall risk.

Method

Participants

The sample consisted of 154 community-dwelling adults and older adults in Israel who were recruited using a convenience sampling method. Research assistants approached the participants at Ono Academic College. The exclusion criteria included the existence of any progressive or acute medical conditions[11,27], mobility issues requiring the use of walking aids, and suspected mild cognitive impairment as defined by the Montreal Cognitive Assessment (MoCA) < 26/30[28]. Candidates with a previous diagnosis of hearing impairment or individuals using hearing aids were also excluded. After signing an informed consent form and completing the MoCA questionnaire, the participants were administered hearing and balance tests. Six participants who scored below 26 on the MoCA were excluded. This left a sample of 148 community-dwelling adults (84 females and 64 males) aged 18–90 years (M = 54.43, SD = 13.71). Younger and older adults were recruited to evaluate AIADH as a predictor of balance problems and risk of falling, with increasing age. The participants' MoCA scores ranged from 26 to 30 (M = 27.55, SD = 1.36). This study was approved by the institutional review board for the protection of human subjects of Ono Academic College (201909ono).

Measures and procedure

All participants underwent two objective hearing tests (Standard Pure-Tone Audiometry test and Words-in-Noise—WIN), one self-reported hearing inventory (the Hebrew version of the Amsterdam Inventory for Auditory Disability and Handicap—H-AIADH; see supplementary material SI1), one balance test (Timed Up and Go—TUG), the Activity-Specific Balance Confidence Scale (ABC-16) that self-reports balance, and the MoCA[25]. All these tests were administered following standard guidelines and regulations.

Objective hearing in the right and left ears was evaluated using Standard Pure-Tone Audiometry, and the Hebrew version of the Words-in-Noise (HWIN) test[29,30]. To assess hearing thresholds, the Standard Pure-Tone Audiometry[31] was administered at octave levels from 500 to 4000 Hz using a HARP mobile audiometer with TDH-50 earphones (Grason-Stadler Inc, Eden Prairie, MN; Guymark UK Limited, West Midlands, UK). The pure tone average 1 (PTA1) was calculated as the average hearing threshold at 500 Hz, 1000 Hz, and 2000 Hz. PTA1 is regarded as a predictor of the speech reception threshold. The pure tone average 2 (PTA2) was calculated as the average hearing threshold at 1000 Hz, 2000 Hz, and 4000 Hz. PTA2 calculates the relative weight of high frequencies to hearing.

The WIN is a word recognition test that assesses speech perception in the presence of noise[32]. The Hebrew version of the WIN consists of two lists of 35 common consonant-vowel-consonant (CVC) words mixed with 6 speakers' babble at 7 signal-to-noise ratios (SNRs) from 24 to 0 dBSNR in 4 dB increments. The two lists were presented to each participant, one for each ear, for open set identification[11,30]. The total number of correctly identified words and the 50% point in dBSNR (WIN 50% point) for each ear was calculated using the Spearman-Karber Eq[33].

Self-reported hearing was evaluated using the Hebrew version of the AIADH (H-AIADH, see supplementary SI1). This self-reported tool assesses auditory disability (activity limitations) and handicap (participation restrictions) as experienced in daily life. It is composed of 30 items, where each item is divided into two sub-questions labeled *a* and *b*. The *a*-items assess an individual's hearing ability (disability) whereas the *b*-items assess an individual's restrictions. The *b*-items were not used in this study since they relate to hearing aid users who were excluded from the current study. The Amsterdam Inventory covers five subscales: (1) Distinction/identification of sounds (items 4, 5, 6, 17, 23, 24, 26, and 29), (2) Localization of sounds (items 3, 9, 15, 21, and 27), (3) Speech intelligibility in noise (items 1, 7, 13, 19, and 25), (4) Speech intelligibility in quiet locations (items 8, 11, 12, 14, and 20), and (5) Detection of sounds (items 2, 10, 16, 22, and 28). Each sub-scale provides a sub-score, thus indicating which aspect/s of hearing is difficult for the respondent. Each *a*-question has four response categories that are coded as follows: Almost never—4; sometimes—3; often—2; and almost always—1. The total AIADH score is the average score of the five subscales. In general, higher scores correspond to greater hearing difficulty[24,26].

Performance-based balance and risk of falling were assessed using the Timed Up and Go Test (TUG). This widely used assessment tool evaluates balance, functional mobility and risk of falling in various adult populations[34–36]. The test requires the subject to stand up, walk 3 m, turn, walk back, and sit down. The time taken to complete the test is measured in seconds. It is highly correlated with level of balance, risk of falling, and functional mobility. Each participant completed the test 3 consecutive times. The final TUG score is the average score of the three repetitions[37].

Self-reported balance was measured on the Hebrew version of the Activity-Specific Balance Confidence Scale (ABC-16)[38]. The ABC scale was developed to quantify individuals' self-perceived level of confidence when performing specific activities without losing balance or becoming unsteady. The ABC scale asks participants to indicate their confidence in doing 16 everyday activities that require transferring, bending, reaching, or walking that vary in difficulty. Each activity is rated on a scale of 0% (not confident) to 100% (completely confident that they will not lose their balance or become unsteady while performing the activity)[38]. The final score is comprised of the sum of the results (0–100%) of each of the 16 questions, divided by sixteen. The ABC is a reliable and valid measure for the assessment of falls and balance-related confidence in older adults[39].

Cognition was assessed using the Hebrew version[40] of the MoCA[28]. This one-page 30-point test takes 10 min to administer. The short-term memory recall task (5 points) involves two learning trials of five nouns and a delayed recall after approximately 5 min. Visuospatial abilities are assessed using a clock-drawing task (3 points) and a three-dimensional cube copy (1 point). Multiple aspects of executive functions are assessed using an alternation task adapted from the Trail Making B task (1 point), a phonemic fluency task (1 point), and a two-item verbal abstraction task (2 points). Attention, concentration, and working memory are evaluated using a sustained attention task (target detection using tapping (1 point), a serial subtraction task (3 points), and forward and backward digits task (1 point each). Language is assessed using a three-item confrontation naming task with low-familiarity animals (lion, camel, rhinoceros; 3 points), repetition of two syntactically complex sentences (2 points), and the aforementioned fluency task. Finally, orientation to time and place is evaluated (6 points)[28].

Statistical analyses

The average scores for each scale and sub-scale were calculated. There were no missing data for the AIADH (total and sub-scales), and there was only one missing data point for the ABC measure. Missing data were not included in the analyses. Standard statistical analyses were conducted on the whole dataset, as specified in the table and figure legends. Standard descriptive statistics were calculated for all the variables (Table 1).

Receiver operating characteristic (ROC) curve analysis was performed using SPSS version 28 software to assess diagnostic utility, using the area under the curve (AUC) to indicate diagnostic accuracy. This included sensitivity and specificity. Two ROC analyses were conducted, one for AIADH and PTA, and one for AIADH and TUG. The ROC analysis for the AIADH measures was conducted to compare its predictive accuracy of TUG, by only using the AIADH item responses and the TUG scoring. Regression analyses were employed throughout the study. All the statistical procedures were performed using SPSS version 28 and the PROCESS macro tool version 4.0[41]. For clarity, the post- hoc analyses for the different age groups even when the interaction was found to be non-significant are presented to better compare the results across the 5 different AIADH subscales.

Previous studies have shown that a TUG score of 10 predicts mobility loss and the frequency of near-fall events. A TUG score of 13.5 is considered to be the cutoff point for identifying increased risk of falling[42,43]. Hence, the AIADH score that predicted a TUG score of 10 was calculated here, by applying the mathematical formula of $Y = 5.04 + 2.26^{*}X$.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Results

The analyses compared the self-reported AIADH scores to objective hearing status, balance problems, and risk of falling.

Table 1 presents the means, standard deviations, and correlational analyses.

AIADH and objective hearing measures

Moderate significant positive correlations (Pearson *r*'s from 0.37 to 0.47; all *p*.'s < 0.001) were found between the AIADH total score and objective hearing measures (PTA1 and PTA2 for both ears). There were also moderate-weak significant positive correlations between the AIADH total score and the objective hearing in noise measures (WIN 50% point) for both ears (rright = 0.36, $p < 0.001$; rleft = 0.22, $p = 0.007$).

On the AIADH sub-scales, weak-moderate significant positive correlations (*r*'s ranging from 0.26 to 0.54; all *p*.'s < 0.001) were found between the AIADH 5 sub-scale scores and the objective hearing measures (PTA1 and PTA2 for both ears). Similarly, weak-moderate significant positive correlations (*r*'s ranging from 0.23 to 0.34; all *p*.'s < 0.01) were found between the AIADH 5 sub-scales scores and the objective hearing in noise measures (WIN 50% point) for the right ear. By contrast, for the left ear there were minimal to no correlations (*r*'s ranging from 0.09 to 0.21) on the scores for the five AIADH sub-scales and the objective measure of hearing in noise (WIN 50% point).

Age was positively and significantly associated with PTA1 and PTA2 and WIN 50% for the right and left ears (r's ranging from 0.21 to 0.46; all *p*.'s < 0.05). Age was positively and significantly associated with AIADH total ($r = 0.19$, $p = 0.019$) and sub-scales (r's ranging from 0.20 to 0.33; all p.'s < 0.05) (except for the discrimination sub-scale). Finally, gender was significantly associated with PTA2 for the left and right ears, WIN50% for the left ear, and AIADH total, localization, noise, and detection subscales. Males presented greater hearing deterioration on the high frequency thresholds (PTA2), WIN50% scores for the left ear and the AIADH scores.

Four additional regression analyses were conducted to predict the objective hearing measures of the right and left ears (PTA 1 & 2) on the AIADH for three different age groups (younger participants, 1 SD from the mean age < 39.72y, participants representing the mean between −1SD and +1 SD, 39.72y < age < 67.14y and older participants, more than 1 SD from the mean age > 67.14y). Simple slope analyses indicated that the older the participants, the more the PTA1 and PTA 2 variance was explained by total AIADH score (see Fig. 1 for the PTA 2 for the right ear, and the complete results including tables and figures in Supplementary SI2, SI3). The results indicated that the older the participant, the better the AIADH predicted the objective hearing measures for both ears. The statistical power for the right ear was more significant than for the left ear (see values in Tables S4 and S5).

Sensitivity and specificity analyses. ROC curve analyses for each of the objective hearing measures and the AIDAH indicated an AUC of 0.74 for PTA 1 for the right ear, an AUC of 0.74 for PTA 2 for the right ear, an AUC of 0.61 for PTA 1 for the left ear, and an AUC of 0.67 for PTA 2 for the left ear, suggesting acceptable overall accuracy[44,45].

AIADH and objective balance and risk of falling measure (TUG)

As shown in Table 1, TUG was positively associated with age and the objective hearing measures (PTA1, PTA2, and the WIN 50% point of both ears) (*r*'s ranging from.17 to.28; all *p*.'s < 0.05) as well as with the total AIADH and all sub-scale scores (*r*'s ranging from 0.35 to 0.44; all *p*.'s < 0.001). The ABC scores were negatively and significantly associated with age ($r = -0.23$, $p < 0.01$) and the objective hearing measures (PTA1 and PTA2 for both ears, WIN 50% of the right ear) (*r*'s ranging from −0.18 to −0.27; all *p*.'s < 0.05) (except for the WIN 50% left ear sub-scale) as well as with the total AIADH and all sub-scale scores (*r*'s ranging from −0.26 to −0.42; all *p*.'s < 0.001).

Since age was significantly associated with the balance measures whereas gender was only associated with some of the hearing measures, additional analyses were conducted to determine the validity of the total AIADH and sub-scales in predicting balance problems for both the objective (TUG) and subjective (ABC) measures. Specifically, six regression analyses were conducted, one for the total AIADH score and one for each of the five AIADH sub-scale scores to predict TUG and the moderating role of age after controlling for the effects of gender. Table 2 presents the regression results similar to those when not controlling for gender.

As shown in Table 2, the total and the five AIADH sub-scale scores strongly and significantly predicted TUG after controlling for the effects of both age and gender. Age was highly positively associated with TUG

Table 1 | Means, standard deviations and inter-correlations for the age, hearing and balance variables

	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Gender	1.57	0.50	–														
2. Age	54.43	13.71	−0.11	–													
3. R_PTA_1	18.03	8.97	−0.09	0.25**	–												
4. L_PTA_1	18.95	10.13	−0.09	0.32***	0.79***	–											
5. R_PTA_2	19.65	11.35	−0.24**	0.42***	0.88***	0.79***	–										
6. L_PTA_2	20.77	12.33	−0.24**	0.46***	0.74***	0.91***	0.85***	–									
7. R-WIN-50	4.67	4.15	−0.11	0.27***	0.36***	0.34***	0.40***	0.41***	–								
8. L-WIN-50	4.82	4.41	−0.20*	0.21*	0.31***	0.27***	0.41***	0.37***	0.52***	–							
9. AID- Tot	1.38	0.34	−0.22**	0.19*	0.41***	0.37***	0.47***	0.40***	0.36***	0.22**	–						
10. AID-Disc	1.24	0.32	−0.14	0.13	0.26***	0.26**	0.34***	0.31***	0.25**	0.14	0.82***	–					
11. AID-loc	1.36	0.47	−0.21*	0.20*	0.34***	0.37***	0.40***	0.35***	0.23**	0.09	0.84***	0.66***	–				
12. AID-Nois	1.42	0.51	−0.27***	0.33***	0.42***	0.39***	0.54***	0.45***	0.34***	0.21*	0.88***	0.71***	0.70***	–			
13. AID-Quiet	1.29	0.38	−0.14	0.23**	0.31***	0.30***	0.38***	0.31***	0.26**	0.14	0.84***	0.74***	0.64***	0.77***	–		
14. AID-Detc	1.26	0.38	−0.23**	0.22**	0.42***	0.42***	0.47***	0.43***	0.32***	0.20*	0.90***	0.72***	0.78***	0.82***	0.70***	–	
15. TUG	8.17	1.76	0.02	0.51***	0.27***	0.23**	0.28***	0.28***	0.28***	0.17*	0.44***	0.35***	0.36***	0.42***	0.40***	0.39***	–
16. ABC	91.45	10.60	−0.14	−0.23**	−0.27***	−0.20*	−0.27***	−0.22**	−0.18*	−0.09	−0.36***	−0.28***	−0.26***	−0.42***	−0.39***	−0.27***	−0 .36***

Gender: 1 = male, 2 = female; See table S6 for exact *p*-values.

AID The Amsterdam Inventory for Auditory Disability and Handicap (AIADH) score, *Tot* total, *R* right, *L* left, *WIN* words in noise, *PTA* pure tone average, *Disc* discrimination of sounds, *Loc* auditory localization, *Nois* intelligibility in noise, *Quiet* Intelligibility in a quiet setting, *Detc* detection of sounds, *TUG* timed up and go, *ABC* activities-specific balance confidence scale, *M* mean, *SD* standard deviation.

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

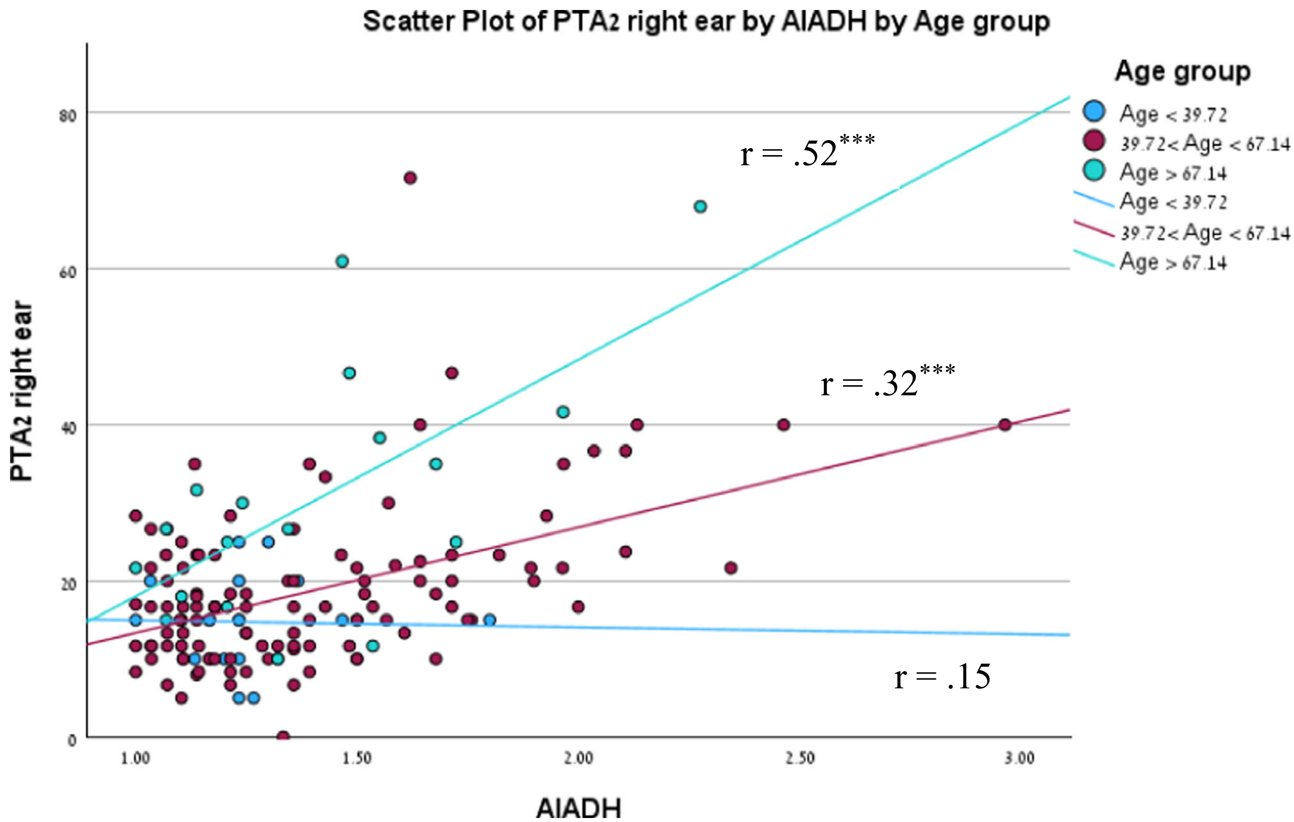

Fig. 1 | AIADH prediction of PTA2 for the right ear for different age groups (all participants). Simple slope analyses indicate that the older the participants, the more the PTA2 variance was explained by the total AIADH score. AIADH Amsterdam Inventory for Auditory Disability and Handicap, PTA2 Pure Tone Average of 1000, 2000, and 4000 Hz, *r* correlation coefficient.

($\beta = 0.49$, $p < 0.001$). The total AIADH interacted significantly and positively with age in predicting TUG, indicating that the power of the prediction of TUG differed across the three age groups. For the five AIADH subscales, significant interactions were found between detection and the discrimination sub-scales and age in predicting TUG, indicating that the power of the prediction of TUG varied across the three age groups.

Simple slope analyses[46] for the total AIADH revealed that the AIADH score was more positively associated with TUG the older the participant (see Table 2). Figure 2 presents the results for the total AIADH prediction of TUG by age for the three age groups (younger participants, 1 SD from the mean age < 39.72y; participants representing the mean between −1SD and +1 SD, 39.72y < age < 67.14y and older participants, more than 1 SD from the mean age > 67.14y).

As shown in Fig. 2, the regression analyses indicated that the older the participants, the more the TUG variance was explained by AIADH total. This suggests that objective balance status measures can be predicted by AIADH self-reported scores.

The 5 AIADH subscales significantly predicted TUG. In terms of the interaction between each of the AIADH subscales and age, the results revealed significant interactions between the detection and the discrimination subscales and age, where the older the participant, the better the prediction of TUG. The AIADH detection subscale of the older age group was the best predictor of TUG ($\beta = 0.87$, $p < 0.001$) (see Table 2).

Sensitivity and specificity analyses. A ROC curve analysis for the TUG and AIDAH measures indicated an AUC of 0.82, suggesting acceptable overall accuracy[44].

Based on the mathematical formula of $Y = 5.04 + 2.26*X$, an AIADH score of 2.20 was found to predict a TUG of 10, and an AIADH score of 3.74 predicted a TUG score of 13.5.

AIADH and subjective balance and risk of falling measure (ABC)

As shown in Table 3, the total and the five AIADH sub-scale scores strongly and significantly predicted TUG after controlling for the effects of age and gender. Age was negatively associated with ABC ($\beta = -0.23$, $p = 0.004$). For the five AIADH subscales, significant negative interactions were found between the detection and the discrimination sub-scales and age in predicting ABC, indicating that the power of the prediction of ABC differed across the three age groups.

The five AIADH subscales significantly predicted ABC. In terms of the interaction between each of the AIADH subscales and age, the results revealed significant interactions between the detection and the discrimination subscales and age, showing that the older the participant, the better the prediction of ABC. The AIADH detection subscale of the older age group was the best predictor of TUG ($\beta = -0.79$, $p < 0.001$) (see Table 3).

In terms of the specific sub-scales, the AIADH detection subscale was the best predictor of both TUG and ABC than any of the other subscales (Tables 2 and 3).

AIADH prediction of TUG and ABC over the effects of objective hearing measures

A previous study indicated that objective hearing measures (PTA1 and PTA2) can predict TUG[11]. Therefore, we examined whether AIADH could provide a better explanation for the variance in the TUG and ABC scores after controlling for the effects of hearing thresholds for the left and right ears. To examine whether AIADH would predict TUG and ABC after controlling for the effects of PTA1 and PTA2, further regression analyses were conducted (see supplementary SI2, Table S2 for predicting TUG and Table S3 for predicting ABC). The results indicated that the total AIADH and the five subscale scores predicted TUG after controlling for the effects of the objective hearing measures and gender (all *p*.'s < 0.001). The same results were found for predicting ABC (excluding the detection subscale that

Table 2 | Regression results for self-reported hearing measure predicting balance (TUG) in younger and older adults

Predictor	β	SE	t	p	LLCI 95%	ULCI 95%	β	SE	t	p	LLCI 95%	ULCI 95%	β	SE	t	p	LLCI 95%	ULCI 95%
	Total						Localization						Quiet					
AIADH	0.32***	0.07	4.51	<0.001	0.181	0.463	0.24**	0.08	3.21	0.002	0.094	0.394	0.28***	0.07	3.98	<0.001	0.142	0.423
Age	0.49***	0.07	7.41	<0.001	0.356	0.612	0.50***	0.07	7.04	<0.001	0.361	0.644	0.47***	0.07	6.59	<0.001	0.327	0.606
AIADH*Age	0.17*	0.08	2.19	0.031	0.017	0.331	0.16	0.09	1.77	0.080	-0.020	0.348	0.09	0.08	1.06	0.291	−0.076	0.251
Gender	0.18**	0.07	2.76	0.007	0.051	0.309	0.15*	0.07	2.13	0.035	0.011	0.286	0.13	0.07	1.88	0.062	−0.006	0.259
−1SDage	0.26**	0.08	3.04	0.003	0.092	0.432	0.19*	0.09	2.02	0.046	0.004	0.370	0.25	0.09	2.98	0.299	0.085	0.420
SDage	0.35***	0.07	5.22	<0.001	0.218	0.485	0.27***	0.07	3.79	<0.001	0.130	0.414	0.30	0.07	4.38	0.075	0.163	0.432
+1SDage	0.39***	0.09	4.16	<0.001	0.204	0.571	0.37***	0.08	4.46	<0.001	0.205	0.532	0.35***	0.08	4.46	<0.001	0.194	0.504
	Discrimination						Noise						Detection					
AIADH	0.27***	0.07	4.07	<0.001	0.138	0.399	0.29***	0.08	3.61	<0.001	0.132	0.453	0.50**	0.16	3.06	0.003	0.176	0.816
Age	0.48***	0.07	7.43	<0.001	0.354	0.610	0.43***	0.08	5.78	<0.001	0.286	0.583	0.54***	0.08	7.19	<0.001	0.390	0.686
AIADH*Age	0.16*	0.06	2.52	0.013	0.034	0.285	0.07	0.08	0.82	0.417	−0.096	0.232	0.49*	0.19	2.56	0.012	0.111	0.862
Gender	0.14*	0.07	2.10	0.038	0.008	0.275	0.17*	0.07	2.43	0.016	0.032	0.309	0.18*	0.07	2.60	0.010	0.043	0.315
−1SDage	0.21**	0.07	2.95	0.004	0.070	0.357	0.27**	0.10	2.76	0.007	0.076	0.462	0.33	0.20	1.64	0.104	−0.068	0.723
SDage	0.30***	0.07	4.53	<0.001	0.167	0.425	0.30***	0.08	4.02	<0.001	0.155	0.454	0.58***	0.15	3.84	<0.001	0.281	0.876
+1SDage	0.39***	0.08	5.14	<0.001	0.240	0.540	0.34***	0.08	4.49	<0.001	0.193	0.495	0.87***	0.16	5.32	<0.001	0.544	1.187

−1SDage = 39.72, SDage = 53.43, +1SDage = 67.14.

R right, *L* left, *PTA* pure tone average, *AIADH* The Amsterdam Inventory for Auditory Disability and Handicap self-report sub-scales, *Disc* discrimination of sounds, Loc auditory localization, *Noise* intelligibility in noise, Quiet intelligibility in quiet settings, *Detect* detection of sounds, *TUG* timed up and go, *β* beta coefficient, SE standard error, *t* t statistical value, *p* statistical significance, *LL* lower limit, *CI* confidence interval, *UL* upper limit.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

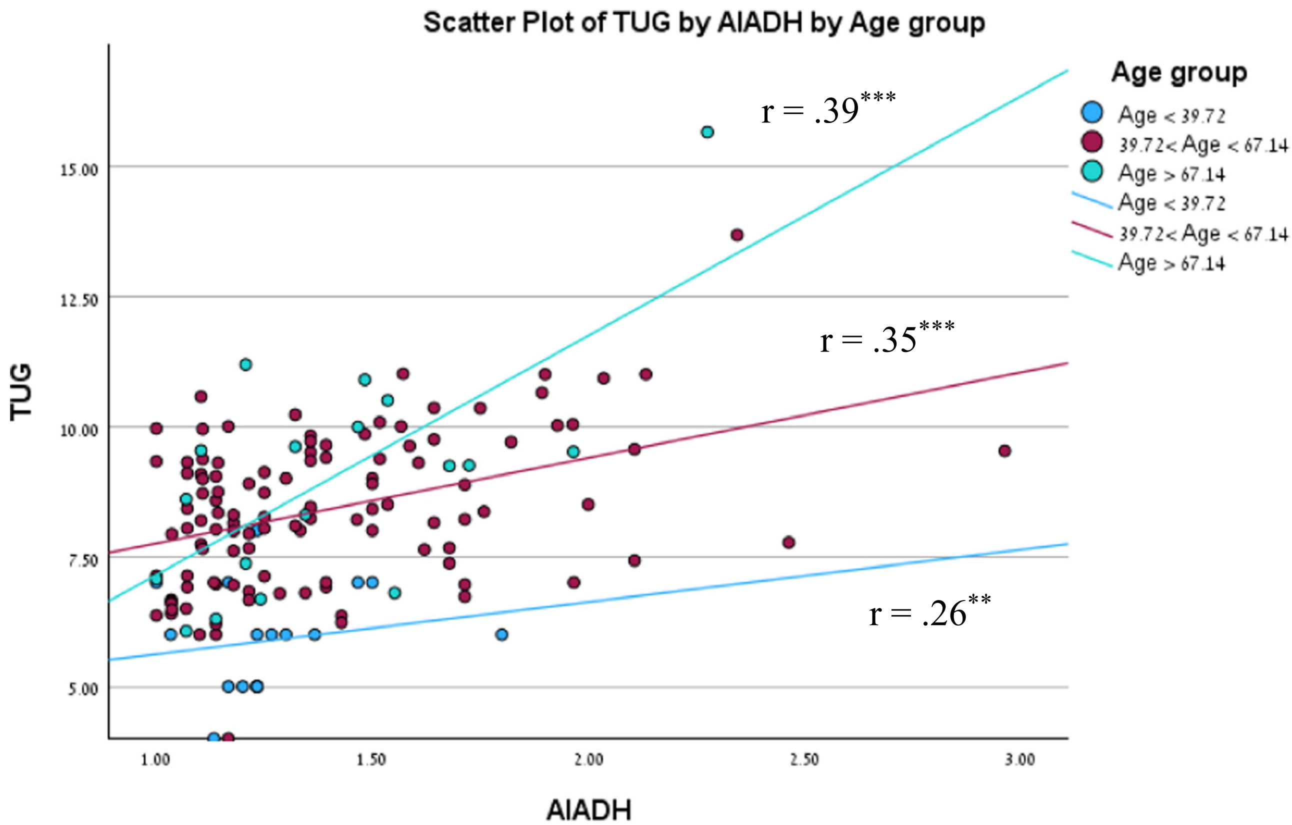

Fig. 2 | AIADH prediction of TUG for different age groups (all participants). The total AIADH prediction of TUG by age for the three age groups (younger participants, 1 SD from the mean age < 39.72y; participants representing the mean between −1SD and +1 SD, 39.72y < age < 67.14y and older participants, more than 1 SD from the mean age > 67.14y). AIADH Amsterdam Inventory for Auditory Disability and Handicap, TUG Timed Up and Go Test, *r* correlation coefficient.

only significantly predicted ABC for the mean age score (SD) and for older participants (+1SD) but not for the younger participants (−1SD)). Thus, the AIADH emerged as an efficient measure for predicting balance status not only for individuals who were not screened by objective hearing measures but also for those who were.

Discussion

The findings suggest that the self-reported AIADH measure can predict not only objective hearing measures (PTA, WIN) but also balance status and risk of falls (TUG, ABC). The data support the administration of the AIADH as an easy-to-use, cost-effective tool for predicting hearing loss, balance status, and increased risk of falling in older adults.

Given the increases in life expectancy, fall prevention is becoming ever more crucial. The number of falls increases in magnitude with age and age-related biological changes such as declines in vision, hearing, somatosensory responses, muscle strength, and coordination[47]. If preventive measures are not implemented in the near future, the number of injuries caused by falls is projected to be 100% higher in 2030[4]. One of the firststeps in preventing falls is the early identification of those at risk of falling and the development suitable prevention programs. Research has shown that intervention strategies, which include hearing rehabilitation and balance exercises, could potentially enhance balance and lessen the risk of falling in various populations[15,46,48–50] but more research is still needed to confirm this.

Modern telemedicine is increasingly relying on remote monitoring[51]. This points to the utility and probable high acceptability of a valid remote screening tool for the early detection of populations at high risk of falling.

The interaction between objective hearing status (PTA) and balance has been extensively documented and shows that hearing loss is a major risk factor for falls[11,13,52–54]. Objective hearing status provides important and useful information to the audiologist; however, these do not always accurately reflect or coincide with measures of self-reported hearing loss or difficulty[24,55,56]. Subjective measures of hearing difficulty are designed to capture perceived hearing difficulties in daily life. Hearing difficulties, more so than objective hearing status, are related to reduced quality of life[57,58]. The current findings pointed to a strong association between self-reported hearing status (AIADH), balance status, and risk of falling in older adults. This suggests that AIADH may be a valid tool for the early detection of balance problems in adults over 40 years of age, and even more so in older adults above 67y (Fig. 2). The absence of an interaction between AIADH and TUG/ABC for the younger group (<40y) may be due to the fact that their hearing levels were within normal limits. The results showed that an AIADH score of 2.20 was found to predict a TUG of 10, which is indicative of possible mobility loss and the frequency of near fall events[42,43], and that an AIADH score of 3.74 predicted a TUG score of 13.5, which is considered to be the cutoff point for identifying an increased risk of falling[42,43].

AIADH predicted both objective and self-reported balance measures beyond the effects of objective hearing status (PTA), thus further confirming the value of this tool for the early detection of risk of falling. Crucially, each AIADH subscale in itself can predict balance status and risk of falling in older adults. This validates the use of AIADH as a tool that reflects the functional changes in hearing that contribute to balance status and risk of falling. In the groups of older adults (above age 40), the detection subscale showed the strongest association with balance and risk of falling. The questions on the detection subscale depict situations where awareness of environmental sounds is important such as being able to hear birds outside, a washing machine running in the house, or someone coming up from behind[59]. This implies that being able to hear environmental sounds is an important component for maintaining one's balance.

The spatial orientation of the body allows individuals to perceive their environment and act accordingly, particularly in cases of movement or destabilization. Although auditory information is not considered to be a fundamental signal in balance control, the auditory system is a perceptual

Table 3 | Regression results for self-reported hearing measure predicting self-reported balance (ABC) *in younger and older adults*

Predictor	β	SE	t	p	LLCI 95%	ULCI 95%	β	SE	t	p	LLCI 95%	ULCI 95%	β	SE	t	p	LLCI 95%	ULCI 95%
	Total						Localization						Quiet					
AIADH	−0.33***	0.09	−3.86	<0.001	−0.505	−0.163	−0.22*	0.09	−2.43	0.016	−0.389	−0.040	−0.34***	0.08	−4.18	<0.001	−0.504	−0.181
Age	−0.23**	0.08	−2.91	0.004	−0.378	−0.072	−0.26**	0.08	−3.13	0.002	−0.424	−0.095	−0.21*	0.08	−2.59	0.011	−0.366	−0.049
AIADH*Age	−0.17*	0.09	−1.76	0.081	−0.352	0.021	−0.20	0.11	−1.89	0.061	−0.417	0.010	−0.13	0.09	−1.40	0.163	−0.317	0.054
Gender	−0.28**	0.08	−3.65	<0.001	−0.434	−0.129	−0.25**	0.08	−3.11	0.002	−0.411	−0.091	−0.23**	0.08	−3.02	0.003	−0.380	−0.079
−1SDage	−0.28**	0.10	−2.66	0.009	−0.482	−0.071	−0.14	0.11	−1.34	0.184	−0.357	0.069	−0.30**	0.10	−3.04	0.002	−0.490	−0.104
SDage	−0.36***	0.08	−4.45	<0.001	−0.523	−0.201	−0.25**	0.08	−2.99	0.003	0.414	−0.084	−0.37***	0.08	−4.67	<0.001	−0.519	−0.210
+1SDage	−0.46***	0.09	−5.26	<0.001	−0.632	−0.287	−0.37***	0.10	−3.85	<0.001	0.559	−0.179	−0.44***	0.09	−4.98	<0.001	−0.618	−0.267
	Discrimination						Noise						Detection					
AIADH	−0.26**	0.08	−3.27	0.001	−0.414	−0.102	−0.39***	0.09	−4.53	<0.001	−0.561	−0.220	−0.44*	0.21	−2.13	0.035	−0.851	−0.031
Age	−0.23**	0.08	−2.97	0.004	−0.377	−0.076	−0.17*	0.08	−2.08	0.039	−0.324	−0.009	−0.29**	0.09	−3.19	0.002	−0.462	−0.109
AIADH*Age	−0.16*	0.07	−2.11	0.036	−0.304	−0.010	−0.16	0.09	−1.80	0.074	−0.333	0.016	−0.46*	0.23	−2.01	0.047	−0.915	−0.007
Gender	−0.24**	0.08	−2.97	0.004	−0.393	−0.079	−0.32***	0.08	−4.30	<0.001	−0.468	−0.173	−0.28***	0.08	−3.47	<0.001	−0.443	−0.121
−1SDage	−0.20*	0.09	−2.35	0.020	−0.374	−0.032	−0.34**	0.10	−3.23	0.002	−0.540	−0.130	−0.28	0.26	−1.10	0.274	−0.787	0.224
SDage	−0.29***	0.08	−3.65	<0.001	−0.439	−0.131	−0.42***	0.08	−5.19	<0.001	−0.576	−0.258	−0.52**	0.19	−2.71	0.008	−0.898	−0.140
+1SDage	−0.38***	0.09	−4.20	<0.001	−0.555	−0.200	−0.51***	0.08	−6.28	<0.001	−0.671	−0.350	−0.79***	0.20	−4.04	<0.001	−1.18	−0.404

−1SDage = 39.72, SDage = 53.43, +1SDage = 67.14.

R right, *L* left, *PTA* pure tone average, *AIADH* The Amsterdam Inventory for Auditory Disability and Handicap self-report sub-scales, *Disc* discrimination of sounds, *Loc* auditory localization, *Noise* intelligibility in noise, *Quiet* intelligibility in quiet settings, *Detect* detection of sounds, *TUG* timed up and go, β beta coefficient, *SE* standard error; *t* t statistical value, *p* statistical significance, *LL* lower limit, *CI* confidence interval, *UL* upper limit.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

system which, with vision and somatosensory responses, is involved in the perception of the dynamics of the environment and in complex representations of 3D space. Therefore, using multiple senses to perceive environmental characteristics enables a more inclusive detection of objects and events, leading to more accurate orientation behavior[21,60,61]. Thus, the detection subscale of the AIADH constitutes an important component for capturing spatial perception.

To the best of our knowledge, this is the first time a self-reported hearing measure has been found to be a valid measure for balance status and risk of falling in older adults. Previous research using the Hearing Handicap Inventory scores (HHIE)[10] reported that an increase in HHIE was associated with increased risk of falling. Heitz et al. [32] also reported higher rates of falls in subjects with self-reported hearing loss using a single survey question.

The current study supports previous findings emphasizing the importance of hearing ability in the right ear for maintaining balance[11]. Wächtler et al. [62] posited that higher cognitive load had a more pronounced effect on the right ear. This suggests that increasing the cognitive demand on a specific feature such as memory, may result in an increased right ear advantage. Aging can cause declines in the efficiency of working memory, which can contribute to higher cognitive load[63]. Hence the stronger interaction between balance status and hearing of the right ear in the older age group in the current study may have resulted from increased cognitive load.

Previous studies have shown that AIADH is a valid predictor of objective hearing loss such that the higher the average pure tone threshold, the greater the self-reported hearing difficulties[12,23–26,64]. The current study found similar results for the Hebrew version of AIADH (H-AIADH, supplementary SI1). Moreover, each of the 5 H-AIADH subscales was significantly associated with objective hearing measures, and not only the total H-AIADH score, as reported in previous studies[20,58,59]. These subscales are important because clinical tests for auditory acuity do not encompass daily activities. The results here support clinical findings on the use of AIADH to detect hearing difficulties, hearing screening, and the evaluation of patients with auditory processing disorder[65].

The current study examined a population of community-dwelling adults, without reported balance or hearing disorders. Future studies focusing on pathological populations with diagnosed hearing impairments, motor limitations, or balance difficulties would provide a better understanding of the interactions between hearing, balance, and the risk of falling. Moreover, in the current study, balance and risk of falling were evaluated with TUG and ABC. Additional tests for balance and risk of falling such as measuring sway on a force plate, the Romberg test, and a documented history of falls could provide greater insights into this relationship. Altogether a 148 adults aged 18-90 participated in the current study. Future work should examine the efficacy of AIADH as a screening tool in a larger cohort, and with a range of populations, to assess its potential to detect high-risk populations and promote early intervention through telemedicine.

Conclusions

AIADH is an important tool for predicting and detecting hearing deterioration, balance problems and the risk of falling. The older the individual, the higher the predictive validity of the AIADH self-report measure for TUG, ABC, and hearing thresholds (PTA). This self-reported (subjective) questionnaire (AIADH) is complementary to the objective hearing measure (PTA) and balance measurements (TUG/ABC). Since AIADH can be administered remotely, it is a strong candidate as a screening tool for the early detection of individuals at risk of hearing loss, balance problems, and risk of falling. With the increasing use of telemedicine in more extensive populations, health authorities and decision-makers should consider the use of AIADH as a screening tool for both hearing deterioration and balance problems.

Data availability

All data generated or analyzed during this study, including source data, are included in this published article and its supplementary information files. The main data set, including the figure images is available by application directly through OSF and can be found at https://doi.org/10.17605/OSF.IO/U8XBV[66]. Source data which refers to the numerical values underlying Figs. 1, 2 in this article are available via the same DOI.

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Author contributions
H.P-K., E.B., and N.H. conceptualized the study, E.Y. analyzed and interpreted the data, H.P-K., E.B., and E.Y., wrote the manuscript. H.P-K., and N.H. were responsible for the data curation. All authors read and approved the final manuscript.

Competing interests
The authors declare no competing interests

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Correspondence and requests for materials should be addressed to Hanna Putter-Katz.

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