


A Systematic Review of the Effect of Hearing Aids on Static and Dynamic Balance in Adults with Hearing Impairment

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Abstract

This preregistered systematic review examined the peer-reviewed scientific literature to determine the effect of hearing aids (HAs) on static and dynamic balance in adults with Hearing Impairment (HI). A search of the English language literature in seven academic databases identified 909 relevant articles published prior to July 2021. Ten articles contained studies that met the inclusion criteria for this review. Seven studies had measured static balance with five reporting improvements and one reporting no changes in balance with HA use. Two studies had measured dynamic balance with both reporting no changes with HA use. One study had measured both dynamic and static balance and reported no changes with HA use. For adults with HI, the evidence was equivocal that amplification from HAs improves balance. High quality studies investigating the effect of HAs on balance in adults with HI are needed given this field is likely to develop in response to the growing population of adults with hearing and balance impairment worldwide.

Keywords

hearing aids, hearing impairment, balance, postural stability, vestibular impairment

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Introduction

The generic term “balance” describes the ability to maintain a stable and specific orientation in relation to the immediate environment with static balance describing the ability to hold the body in a specific position and posture and dynamic balance describing the ability to maintain balance when the body is in motion. Balance is achieved through the complex integration of multiple sensory inputs (Melzer et al., 2001) including vision (Ray et al., 2008), somatosensation (Simoneau et al., 1995), vestibular inputs (Shumway-Cook & Horak, 1986), and the more recently suggested input of hearing (Campos et al., 2018). The similarly generic term “balance problems” describes the falls, postural instability, and/or vestibular impairment that can result from a failure in one or more sensory inputs to balance and/or their integration. Balance problems are prevalent in both general and clinical populations (Murdin & Schilder, 2015) with management options dependent on aetiology. This review considers the use of hearing aids (HAs) to manage balance problems in adults with Hearing Impairment (HI).

The association of balance problems with HI in adults stems from their high rates of co-occurrence (Agrawal et al., 2012; Berge et al., 2019; Murdin & Schilder, 2015; Zuniga et al., 2012) and suggestions that poorer hearing thresholds could be associated with increased risk of postural instability (Berge et al., 2019; Thomas et al., 2018). The latter includes reports of the chance of falling increasing by 2.39 in the presence of HI (Jiam et al., 2016) and by 1.4 with every 10 dB increase in HI (Lin & Ferrucci, 2012).

The co-occurrence of balance problems and HI could be due to several factors, both direct and indirect (Berge et al., 2019). Direct factors include the proximity and shared

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anatomy and physiology of the vestibular and hearing end organs in the inner ear and their associated innervation via the VIIIth cranial nerve and brainstem (Berge et al., 2019; Santos et al., 2015). Such proximity increases the probability of an impairment in one system affecting the other system (e.g., Meniere's disease, acoustic neuromas, and vestibular labyrinthitis). Indirect factors include processes that can simultaneously affect both balance and hearing such as the non-pathological process of ageing (Agmon et al., 2017; de Almeida Ciquinato et al., 2020) or pathological processes such as diabetes (Frisina et al., 2006), thyroid problems (Bellman et al., 1996), and oto-vestibulotoxic medication (Chen et al., 2007).

The suggestion that HAs could be used to improve balance in adults with HI stems from two main factors. The first factor argues that hearing could serve as a fourth sensory input in the maintenance of balance (after vision, somatosensation and input from the vestibular system) (Campos et al., 2018; Gandemer et al., 2017). This argument proposes that listeners use monaural and binaural cues to create three-dimensional, spatial hearing maps of the surrounding environment (Campos et al., 2018; Gandemer et al., 2017). Listeners then use these maps to locate themselves relative to static and dynamically changing sound sources in their environment (Eddins & Hall, 2010). Support for this hypothesis can be drawn from studies showing adults with normal hearing can improve their balance when given access to auditory cues that are stationary (Gandemer et al., 2017; Zhong & Yost, 2013) or dynamic (Deviterne et al., 2005; Tanaka et al., 2001). The second factor argues that hearing competes with balance (and other functions) for limited cognitive resources in the brain (Lau et al., 2016). This argument proposes that the presence of unmanaged HI could see the listener needing to draw on cognitive resources to support hearing over balance. This competition could result in listeners allocating insufficient cognitive resources to maintain balance (Hofer et al., 2003).

Given the two factors described above, it is possible that HAs could improve balance in adults with HI by enhancing access to auditory cues and/or reducing the need for cognitive resources. These possibilities have recently been the target of at least two systematic reviews (Borsetto et al., 2021 and Ernst et al., 2021). Borsetto et al. (2021) reviewed the influence of HAs on balance control in adults with mild to severe sensorineural HI and concluded that HAs could improve balance in adults with HI in certain conditions. Ernst et al. (2021) reviewed the impact of diagnosed and treated HI (including HAs and cochlear implants) on balance and the risk of falls and concluded that hearing amplification is most likely to improve balance in elderly. Despite both reviews contributing significantly to our knowledge of HAs and balance, both reviews lacked a quality assessment of the included studies, a detailed description of the audiological data presented in the reviewed studies, and registration with the International Prospective Register of Systematic

Reviews. A third review by Carpenter and Campos (2020) should also be considered for its claim that any conclusion on the effect of HAs on balance is premature. Whilst also contributing to our knowledge of HAs and balance, this review's use of strict inclusion criteria limited its review of HAs and balance to three studies that had used well-defined posturography measures to assess balance in adults with hearing loss with and without their HAs (Maheu et al., 2019; Negahban et al., 2017; Vitkovic et al., 2016; all of which are included in the current review). The remaining studies reviewed by Carpenter and Campos (2020) investigated balance in adults with cochlear implants and adults with normal hearing that had been suppressed.

In this registered systematic review, we examine the peer-reviewed scientific literature to determine the efficacy of HAs on static and dynamic balance in adults with HI. We include details of quality assessments of selected studies and present detailed hearing and balance data extracted from the studies. This review sought to answer the following research question presented in the PICO (Population, Intervention, Comparison, Outcome) format of Needleman (2003): In adults with HI (P), does amplification with HAs (I) improve static and dynamic balance (O) compared to no amplification (C).

Methods

The protocol and methods used in this review were registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD 42020194035, 5th September 2020). The review method followed the guidelines established by the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA-P) (Shamseer et al., 2015).

Search Strategy

An extensive, computer-based, systematic search of the literature was completed using the following databases: PubMed, Embase, Web of Science, Scopus, Cochrane library (including Central), Medline, and CINAHL. The search was originally conducted in May 2020 and repeated in October 2021 in order to include any papers published since the original search. Reference lists and citation tracking were screened to identify any additional relevant studies, and Google Scholar was used to identify further gray literature.

The search strategy was developed and tested through an iterative process by an experienced medical information librarian in consultation with the review team. The database search terms were: HI OR hearing loss OR presbycusis OR hard of hearing AND hearing aid* OR listening device OR hearing device OR auditory intervention OR auditory amplification AND postural stability OR postural balance OR balance OR dizziness OR vertigo OR gait OR posture OR dynamic posture OR static posture OR vestibular impairment* OR

Table 1. Study Inclusion Criteria Defined in Terms of the PICO Question.

P (Population)	Adults aged ≥ 18 years with any type of hearing impairment ≥ 20 dBHL.
I (Intervention)	At least one group of participants fitted with HAs (unilateral or bilateral).
C (comparison)	Either a within-group comparison (HAs on vs off) or a between-group comparison (aided group vs unaided group).
O (outcome)	Any measure of balance, postural stability, gait, or vestibular function.

Note: HA = Hearing aids.

vestibular disorder*. There were no date restrictions on any of the searches. The full search strategy is reported in the supplementary material.

Study Inclusion Criteria

The study inclusion criteria were based on the PICO format (Needleman, 2003) of the research question (see Table 1).

Study designs that were considered for this review were Randomised Control Trials (RCTs), cross-sectional studies, retrospective studies, case reports, and observational studies. Systematic reviews, single case reports, clinical handbooks, books, and studies with non-human participants were excluded from the review. Studies were also excluded if the outcome measure of balance was limited to self-reports of falls only, or if the report was written in a language other than English.

Study Selection and Inter-Rater Reliability

A standardized data collection form was developed in Covidence (www.covidence.org). Detailed guidance notes were developed and piloted by the first author and shared with two other reviewers to ensure consistency. The search strategy (Figure 1, adapted from PRISMA flowchart [Moher et al., 2009]) initially yielded a total of 1335 articles of which 426 were duplicates. The title and abstracts of the 909 identified articles were screened independently by two reviewers for inclusion using the study selection criteria. The conflict error between the two reviewers during this title and abstract screening round was $<3\%$. Any conflicts were resolved by discussion between the reviewers and with the other authors where needed. A total of 24 articles met the eligibility criteria for a full review by two reviewers against the inclusion and exclusion criteria, of which 10 met the eligibility criteria for inclusion in the present systematic review. The conflict error between the two reviewers during this full article review round was 8.3% (2 articles). These conflicts were resolved by discussion between the reviewers and the other authors.

Data Extraction and Synthesis

The first author used a checklist of items relevant to the present study's inclusion criteria to extract elements about the study design and relevant results from the ten articles included in the review (Table 2). Data was included from participants with HAs and participants from other groups if that group's performance on a balance task was compared to the HA group. The reliability of the data extraction was checked by the co-authors and discrepancies were resolved through discussion. A meta-analysis of the included data was not possible due to the small number of studies identified and the heterogeneity of study design and balance outcome measures. The extracted data were analyzed using a narrative synthesis which relies primarily on the use of words and text to summarize and explain the findings of the synthesis (Popay et al., 2006).

Quality Assessment and Risk of Bias

Each study was assessed by two reviewers using the Downs and Black (1998) quality checklist. This checklist's high inter-rater reliability (Deeks et al., 2003) and consistency with 18 other recommended quality assessment tools (West et al., 2002) has seen it used in systematic reviews including in the field of audiology (Maidment et al., 2018). The checklist consists of 27 questions relating to the quality of reporting, external validity, internal validity, and statistical power of a study. Each criterion is scored "0" if not evident (or unable to be determined) or "1" if evident. The exception is criterion 5 (description of principle confounders), which is scored "0" if not evident (or unable to be determined), "1" if partially evident, or "2" if evident. The final score for the checklist categorizes a study into one of four quality levels: excellent (scores of 26–28), good (scores of 20–25), fair (scores of 15–19), or poor (scores ≤ 14) (Hooper et al., 2008).

Results

Of the 10 studies included in this review, eight used a single group case series (pretest-posttest) and two used a two group case series research design in which objective measures were obtained in laboratory settings from participants completing balance tasks with and without HAs (Table 2). Seven studies measured static balance, two measured dynamic balance, and one measured both static and dynamic balance of participants. Measures of static balance were performed while the participant was standing still. This often saw the measurement of slow drifts and immediate corrections as the participant attempted to preserve the body's center of mass within its base of support (Collins & De Luca, 1995). Measures of dynamic balance were performed while the participant was moving. This saw a range of measures performed while participants completed different types of

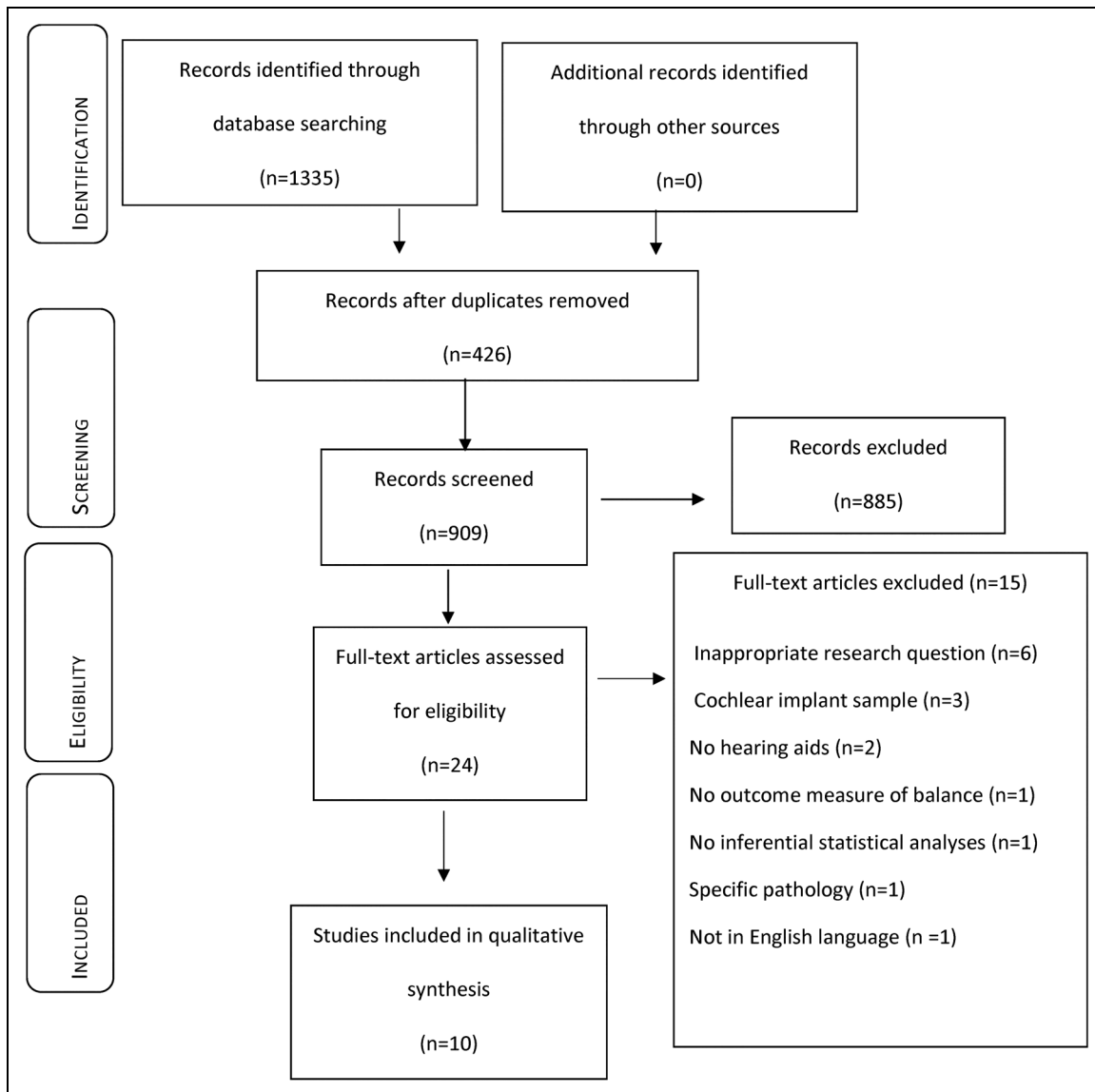


Figure 1. Selection of studies for the systematic review based on preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram.

motion (Baker et al., 2021). Two examples (of many) include the use of inertial sensors to measure changes in center of pressure when walking a fixed distance, and the measurement of changes in the number of steps required to regain balance while walking forward with acceleration on a dual belt treadmill.

Two studies (Maheu et al., 2019 and Negahban et al., 2017) included between-groups measures. Negahban et al. (2017) compared the postural stability of a group of participants with HI who wore HAs to that of a group of participants with HI who did not wear HAs. Maheu et al. (2019) compared the postural stability of a group of participants with confirmed hearing and vestibular impairment who wore HAs to a group with confirmed HI but no vestibular impairment who wore HAs. Eight studies provided no information

regarding the details of the HAs and their settings for their participants. Of the two studies that did offer some details on the HAs, Rumalla et al. (2015) verified the output of the HAs worn by participants by means of insertion gain and Negahban et al. (2017) reported the participants' average aided thresholds.

Participants

One hundred and ninety-nine participants with HI were evaluated in the ten studies included in the review (ranging from 9 to 47 per study). The degree and type of HI varied both within and between studies with degree and type of impairment not reported in Kowalewski et al. (2018), Rumalla et al. (2015), and Weaver et al. (2017), moderate impairment

Table 2. Summary of the ten Studies Included in the Systematic Review. the First Seven Studies Measured Static Balance Only, the Eighth Study Measured Both Dynamic and Static Balance and the Final two Studies Measured Dynamic Balance. the Final two Columns Provide a Simple Indication of the Overall Finding of Each Study Regarding HAs Affecting Static (S) or Dynamic (D) Balance in Adults with Hearing Impairment, Where “Yes” Indicates a Positive Finding (Improvements in Balance with HAs) and “No” Indicates a Negative Finding (no Improvements in Balance with HAs).

Study & research design	Participants	HAs	Methods	Effect of HAs on static or dynamic balance	S	D
Rumalla et al. (2015) Single group case series (pretest-posttest).	<ul style="list-style-type: none"> 14 adults with HI & HAs, 7 female, mean age 77 (range 65–91) years. Hearing thresholds not reported. HI defined as aided thresholds ≥ 25 dB (type not specified) in each ear. No self-reported balance concerns. 	<ul style="list-style-type: none"> ≥ 3 months HA experience. Bilateral. Type not reported. Mean gain 12.75 dB SPL. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs. Test room: not reported, 65 dB SPL BBN (0.1–4 kHz) from 0° azimuth at ear level. 	<ul style="list-style-type: none"> Static: significantly improved results for Romberg on foam (Rof, eyes closed) & tandem stance test (TST, eyes closed on firm surface). Both tests measured the ability to maintain a standing posture for up to 30 s. 	Yes	
Ibrahim et al. (2019) Single group case series (pretest-posttest).	<ul style="list-style-type: none"> 9 adults with HI & HAs, 4 female, mean age 58.5 ± 21.2 years. Moderate to severe SNHL. HI defined as hearing thresholds >30 dB HL. Balance concerns not reported. 	<ul style="list-style-type: none"> ≥ 6 months HA experience. Fitting & type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs. Test room: not reported, 30 dB SPL of 1/3 octave noise (center frequency ~ 3 kHz) from 0° azimuth at ear level. 	<ul style="list-style-type: none"> Static: significantly improved results on Romberg on foam (Rof, eyes closed) & tandem stance test (TST, eye opening and surface not stated). Both tests measured the ability to maintain a standing posture for up to 30 s. 	Yes	
Negahban et al. (2017) Two group case series (one group pretest-posttest & one group posttest only).	<ul style="list-style-type: none"> Group 1 (aided): 22 adults with HI & HAs, 6 female, mean age 67.4 ± 3.5 years. Average hearing threshold 45.40 ± 4.36 dB. Average aided hearing threshold 23.39 ± 4.82 dB. Group 2 (unaided): 25 adults with HI & no HAs, 7 female, mean age 67.1 ± 5.5 years. Average hearing threshold 46.32 ± 8.52 dB. Type of HI not reported. dB type not specified. No self-reported balance concerns. 	<ul style="list-style-type: none"> ≥ 3 months HA experience (mean 33.5 ± 16.68 months). Bilateral. Type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs & between group, aided vs unaided. Test room: reported as “regular room with ambient sound”. 	<ul style="list-style-type: none"> Static: significantly improved CoP SD velocity in the AP & ML planes when standing on a foam surface with eyes open for: 1) Group 1 (aided) when wearing HAs vs not wearing HAs, & 2) Group 1 (aided) when wearing HAs vs Group 2 (unaided). No differences found in other conditions of firm surface, eyes open; firm surface, eyes closed; or foam surface, eyes closed. Group 1 (aided) showed a significant correlation (positive) between CoP SD velocity in the AP plane & time of HA acquisition (earlier HA acquisition associated with better CoP SD velocity). 	Yes	
Maheu et al. (2019) Two group case series (pretest-posttest)*	<ul style="list-style-type: none"> 18 adults with HI & HAs, 11 female, mean age 38.06 (range 21–60) years. Group 1: 8 adults without 	<ul style="list-style-type: none"> HA experience not reported. Bilateral. Type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs; & between group, vestibular impairment vs no vestibular impairment. 	<ul style="list-style-type: none"> Static: significantly reduced somatosensory reliance in adults with HI and vestibular impairment when compared to the HI group. 	Yes	

(continued)

Table 2. Continued.

Study & research design	Participants	HAs	Methods	Effect of HAs on static or dynamic balance	S	D
	<ul style="list-style-type: none"> vestibular impairment. Average SNHL RE 101.25 dB HL & LE 108.54 dB HL. Group 2: 10 adults with vestibular impairment. Average SNHL RE 108.05 dB HL & LE 101.5 dB HL 		<ul style="list-style-type: none"> Test room: not reported, 56–65 dB SPL BBN (0.1 to 4 kHz) from 180° azimuth at ear level. 	<p>This result showed that when wearing HAs, these adults relied less on somatosensory cues when standing on foam vs firm surfaces. Static balance was measured using the modified Clinical Test of Sensory Interaction in Balance (mCTSIB). Participants stood on a force platform that provided CoP recordings of the sway area and sway velocity.</p> <ul style="list-style-type: none"> Static: significant decrease (improvement) in the total path area, maximum CoP displacement in AP direction, averaged sway velocity in both AP and ML with HAs across all 8 conditions. No significant improvement in the CoP displacement in the ML direction with HAs. 		
Ninomiya et al. (2021) Two group case series (pretest-posttest).*	<ul style="list-style-type: none"> 10 older adults with HI & HAs, 5 female, mean age 63.4 (range 62–79) years. Average HI 60 dB HL. Type not reported. No self-reported balance concerns. 	<ul style="list-style-type: none"> Mean HA experience 3.7 years, range 1 to 8 years. Bilateral. Type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs with external sound vs not wearing HAs with no external sound. Test room: anechoic room (ambient noise <15 dB A), 1) no sound 2) white noise at 70 dB A (70–17000 Hz) 1 m anterior to participants at ear level. 	<ul style="list-style-type: none"> Static: significant decrease (improvement) in the total path area, maximum CoP displacement in AP direction, averaged sway velocity in both AP and ML with HAs across all 8 conditions. No significant improvement in the ML direction with HAs. 	Yes	
Vitkovic et al. (2016) Single group case series (pretest-posttest).	<ul style="list-style-type: none"> 19 adults with HI & HAs, 10 female, mean age 64.7 (range 26–79) years. Bilateral (n = 12), asymmetrical (n = 6), & high frequency (n = 1) SNHL. Mean 4fa RE 49 ± 16.7 dB & LE 47.8 ± 13.4 dB HL. HI defined as 4fa ≥ 20 dB HL in both ears. 	<ul style="list-style-type: none"> HA experience not reported. 17 bilateral (4 BTE, 6 RITE, 1 ITE, 2ITC & 3 CIC). 2 unilateral (2 BTE). 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs. Test room: 1) untreated, 2) sound-treated, 3) sound-treated with 60–70 dB SPL WN from 0° azimuth, & 4) sound-treated with 60–70 dB SPL WN moving from -90° to 90° azimuth at ear level. 	<ul style="list-style-type: none"> Static: significantly improved mean CoP path length when wearing HAs with external sound (acoustic conditions 3 & 4) vs without external sound (acoustic conditions 1 & 2). Mean CoP path length (which quantifies the total amount of sway) was measured by standing on a force platform (Nintendo Wii board) in 	Yes	

(continued)

Table 2. Continued.

Study & research design	Participants	HAs	Methods	Effect of HAs on static or dynamic balance	S	D
	<ul style="list-style-type: none"> No self-reported balance concerns. 			<p>each of 4 conditions: 1) firm surface, eyes open, 2) firm surface, eyes closed, 3) foam surface, eyes open, & 4) foam surface, eyes closed, for up to 60 s.</p> <ul style="list-style-type: none"> Static: no change on Sensory Organization Test (SOT) composite score. The SOT involves 6 test conditions: 1) eyes open with fixed visual field and stable platform 2) eyes closed with stable platform 3) eyes open with moving visual field and stable platform 4) eyes open with fixed visual field and unstable platform 5) eyes closed with unstable platform, and 6) eyes open with moving visual field and unstable platform. The SOT measures the anterior to posterior center of gravity displacement and the final composite score across all 6 conditions is averaged giving a percentage sway from 0% (fall) to 100% (no sway). Static & Dynamic: no change on Berg Balance Scale (BBS) where participants rate balance during 14 tasks (sitting, sitting-to-standing, standing, etc.). 		
McDaniel et al. (2018) Single group case series (pretest-posttest).	<ul style="list-style-type: none"> 22 adults with HI & HAs, 3 female, mean age 68.5 (range 58–81) years. Average HI RE 41 dB HL & LE 33 dB HL. Type not reported. Self-reported falling at least once in previous 3 years (n = 7) and concerns regarding balance (n = 5). 	<ul style="list-style-type: none"> Mean HA experience 3.5 years, range 3 months to 10 years. Bilateral. Type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs. Test room: not reported, 65 dB SPL multi-talker babble from 0° azimuth at ear level. 	<ul style="list-style-type: none"> Static: no change on Sensory Organization Test (SOT) composite score. The SOT involves 6 test conditions: 1) eyes open with fixed visual field and stable platform 2) eyes closed with stable platform 3) eyes open with moving visual field and stable platform 4) eyes open with fixed visual field and unstable platform 5) eyes closed with unstable platform, and 6) eyes open with moving visual field and unstable platform. The SOT measures the anterior to posterior center of gravity displacement and the final composite score across all 6 conditions is averaged giving a percentage sway from 0% (fall) to 100% (no sway). Static & Dynamic: no change on Berg Balance Scale (BBS) where participants rate balance during 14 tasks (sitting, sitting-to-standing, standing, etc.). 	No	
Lacerda et al. (2012) Single group case series (pretest-posttest).	<ul style="list-style-type: none"> 28 adults with HI & HAs, 15 female, mean age 70.6 ± 6.6 (range 60–84) years. Bilateral SNHL mild (n = 8), moderate (n = 10), or severe (n = 10). Self-reported vertigo (n = 16). 13 adults with HI & HAs, 6 female, mean age 83 (range 70–95) years. Hearing thresholds not reported. HI defined as unaided hearing thresholds ≥ 30 dB HL in the better ear. No self-reported balance concerns. 	<ul style="list-style-type: none"> 4-months HA experience. Fitting & type not reported. 	<ul style="list-style-type: none"> Within group, pre- vs 4 months post-HA fitting. Test room: not reported. 	<ul style="list-style-type: none"> Static & Dynamic: no change on Berg Balance Scale (BBS) where participants rate balance during 14 tasks (sitting, sitting-to-standing, standing, etc.). 	No	No
Weaver et al. (2017) Single group case series (pretest-posttest).	<ul style="list-style-type: none"> Self-reported vertigo (n = 16). 13 adults with HI & HAs, 6 female, mean age 83 (range 70–95) years. Hearing thresholds not reported. HI defined as unaided hearing thresholds ≥ 30 dB HL in the better ear. No self-reported balance concerns. 	<ul style="list-style-type: none"> Mean HA experience 18.1 years. Bilateral. Type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs. Test room: quiet (background noise < 45 dB), 65 ± 5 dB BBN (0–4 kHz) from 0° azimuth. dB scale not specified. 	<ul style="list-style-type: none"> Dynamic: no changes in time to walk 8 m & the Timed Up & Go (TUG) test. Measurements involved inertial sensors worn over the lumbar spine & ankles to record CoP, gait velocity, stride length, swing time variability, time in double support phase & cadence. 	No	

(continued)

Table 2. Continued.

Study & research design	Participants	HAs	Methods	Effect of HAs on static or dynamic balance	S	D
Kowalewski et al. (2018) Single group case series (pretest-posttest).*	<ul style="list-style-type: none"> 19 adults with HI & HAs, 9 female, mean age 73.2 ± 9.1 years. Self-reported HI. Hearing thresholds not reported. No self-reported balance concerns. 	<ul style="list-style-type: none"> HA experience not reported. Fitting & type not reported. 	<ul style="list-style-type: none"> Within group, wearing HAs vs not wearing HAs. Test room: not reported, 1) no sound & 2) BKB-SIN (level & location not reported). 	<ul style="list-style-type: none"> Dynamic: change in the number of steps required to regain balance may not have improved enough to prevent a fall. Testing conducted while standing on a dual belt treadmill in three balance conditions: 1) stationary, 2) walking forward with an acceleration of 2 m/s², & 3) walking forward with an acceleration of 5 m/s². 		No

Note. All values following the ± are standard deviations; *these studies included adults with normal hearing but their results are not considered here; **4fa** = 4-frequency average; **ABC scale** = Activities-specific Balance Confidence scale (Powell & Myers, 1995); **AC** = air conduction; **AP** = anterior-posterior; **BBS** = broad band noise; **BBN** = broad band noise; **BBS** = Berg Balance Scale (Berg et al., 1992); **BKB-SIN** = Bamford Kowal-Bench Speech-in-Noise test (Bamford & Bench, 1979); **BTE** = Behind the ear; **CIC** = Completely In the canal; **CoP** = Centre of Pressure; **FES-I** = Falls Efficacy Scale-International (Yardley et al., 2005), where participants answer questions about fear of falling; **HA** = Hearing aids; **HI** = Hearing impairment; **HL** = Hearing Level; **ITC** = In the canal; **ITE** = In the ear; **kHz** = kilohertz; **LE** = left ear; **Max** = maximum; **mCTSIB** = modified Clinical Test of Sensory Interaction in Balance (Cohen et al., 1993) that measures CoP sway area and velocity in 4 static conditions: 1) firm surface, eyes open, 2) firm surface, eyes closed, 3) foam surface, eyes open, and 4) foam surface, eyes closed, each held for a maximum of 30 s; **ML** = mediolateral; **RE** = right ear; **RITE** = Receiver In the ear; **Rof** = Romberg on foam (Galán-Mercant & Cuesta-Vargas, 2014), where participants stand on a foam surface with eyes open; **SNHL** = sensorineural hearing loss; **SOT** = Sensory Organization Test (Ford-Smith et al., 1995); **SD** = standard deviation; **SPL** = sound pressure level; **TST** = a tandem stance test (Maki et al., 1994), where participants stand placing one foot in front of the other; heel to toe; **TUG** = Timed Up and Go test (Schoppen et al., 1999), where participants stand up from a seated position, walk for 3m at a comfortable pace, and sit from a standing position; **WN** = white noise.

(type not specified) reported in Ninomiya et al. (2021), mild sloping to severe impairment (type not specified) reported in Negahban et al. (2017) and McDaniel et al. (2018), and moderate to profound sensorineural impairment reported in Ibrahim et al. (2019), Lacerda et al. (2012), Maheu et al. (2019), and Vitkovic et al. (2016).

The 10 reviewed studies showed considerable variability in the reported length of participants' HA use and experience. Five studies included participants with at least 3 months experience with HAs (Ibrahim et al., 2019; McDaniel et al., 2018; Negahban et al., 2017; Rumalla et al., 2015; Weaver et al., 2017). Ninomiya et al. (2021) included participants with at least one year of experience with HAs. Three studies reported that their participants were experienced HA users but did not specify the duration of use (Kowalewski et al., 2018; Maheu et al., 2019; Vitkovic et al., 2016). Lacerda et al. (2012) assessed the balance of their participants pre- and 4 months post-fitting with HAs. Negahban et al. (2017) was the only study to report any correlation results between the time of HA acquisition and balance measures in their participants. Six studies indicated that their participants wore bilateral HAs during the trial (Maheu et al., 2019; McDaniel et al., 2018; Negahban et al., 2017; Ninomiya et al., 2021; Rumalla et al., 2015; Weaver et al., 2017), one study reported both unilateral and bilateral HA use (Vitkovic et al., 2016), and the remaining studies did not specify the laterality of the participants' HA fitting (Ibrahim et al., 2019; Kowalewski et al., 2018; Lacerda et al., 2012). Vitkovic et al. (2016) was the only study to report the types of the HAs used by their participants. Further information regarding the HA features, programming algorithms and average daily use were not reported by any of the studies.

Static Balance Outcome Measures

Two studies (Ibrahim et al., 2019; Rumalla et al., 2015) used the Romberg on foam test and the tandem stance test (TST) to examine maximum hold time up to 30 s to measure the benefits of HAs on static balance. In both studies, the static balance tests were performed with and without HAs. Ibrahim et al. (2019) reported a significant ($p < 0.05$ or better) increase in standing time on the Romberg on foam test for eight out of nine participants with HAs (mean improvement 4.4 s, with one participant showing a ceiling effect in both HA conditions) and on the TST (mean improvement 3.36 s) for all nine participants. Rumalla et al. (2015) reported a significant ($p < 0.005$) increase in standing time on the Romberg on foam test in 10 out of 14 participants with HAs (mean improvement 8.5 s, with four participants showing a ceiling effect in both HA conditions), and a significant increase in standing time with HAs on the TST in all 14 participants (mean improvement 5.3 s). Rumalla et al. (2015) found no significant ($p > 0.05$) correlation between the audiometric gain (mean = 12.75 dB SPL) of HAs and the improvements reported on both tests of static balance.

Four studies (Ninomiya et al., 2021; Maheu et al., 2019; Negahban et al., 2017; Vitkovic et al., 2016) recorded Centre of Pressure (CoP) excursion measures (sway area, sway velocity, mean velocity and/or path length) to assess the postural stability of participants with and without HAs while standing in four different static conditions on force platforms or load cells. Ninomiya et al. (2021) assessed their participants using posturography and reported significant ($p < 0.05$) reductions in the total path area, maximum COP displacement in AP direction, averaged sway velocity in both AP and ML in the presence of an external auditory sound when HAs were used. Maheu et al. (2019) reported that HAs significantly ($p < 0.005$) reduced somatosensory reliance (measured by comparing balance standing with eyes open on foam versus eyes open on a firm surface, and without auditory input versus with auditory input) but not visual reliance (measured by comparing balance standing with eyes closed on firm surface versus eyes open on a firm surface, and without auditory input versus with auditory input) for maintaining balance in 10 participants with hearing and vestibular impairment compared to eight participants with HI only. Maheu et al. (2019) suggested the benefit of HAs for the participants with hearing and vestibular impairment stemmed from greater weighting of auditory cues for maintaining balance to compensate for the loss of somatosensory cues. Negahban et al. (2017) reported significant ($p < 0.0001$) reduced sway in both the anterior-posterior and mediolateral directions in participants with HAs on for the eyes open on foam condition and reported significantly ($p < 0.0001$) reduced sway in both the anterior-posterior and mediolateral directions for the aided group when compared to the unaided group. Vitkovic et al. (2016) used the modified Clinical Test of Sensory Interaction in Balance (mCTSIB) to report a significant ($p < 0.05$) interaction between HA (HA vs no HAs) and acoustic environment (sound vs no sound) conditions. This interaction showed that wearing a HA in the presence of external sound resulted in less sway (better postural stability) than with no external sound.

One study (McDaniel et al., 2018) used the Sensory Organization Test (SOT) to measure the postural stability of a group of adults with HI and HAs. The SOT involves six static conditions of which four resemble the static conditions used by Vitkovic et al. (2016), Negahban et al. (2017) and Maheu et al. (2019). However, McDaniel et al. (2018) failed to find any significant ($p > 0.05$) differences in the SOT composite score of their participants with HAs versus without HAs.

Dynamic Balance Outcome Measures

Two studies by Kowalewski et al. (2018) and Weaver et al. (2017) employed different dynamic measures and showed no significant ($p > 0.05$) improvements in postural stability with HAs.

The first study, Kowalewski et al. (2018), measured the number of steps required to regain balance (reactive balance) while standing on a dual belt treadmill in three balance and auditory conditions in a group of older adults with HI and HAs. The authors reported no significant ($p > 0.05$) difference in the number of steps taken (reactive balance) for the hearing-impaired group when wearing HAs compared to not wearing HAs.

The second study, Weaver et al. (2017), used walking tests to assess the dynamic balance of a group of adults with HI and HAs while HAs were worn and not worn. The authors did not report any significant ($p > 0.05$) differences in the walking speed, stride length variability, swing time variability, double support phase or time needed to complete the Timed Up and Go test for participants wearing HAs compared to not wearing HAs.

Static and Dynamic Balance Outcome Measures

Lacerda et al. (2012) used the Berg Balance Scale (BBS), a clinical test that measures functional balance by scoring the performance of 14 dynamic and static tasks. A group of older adults with HI were fitted with HAs and their balance was assessed before and after 4 months of using HAs. The authors found no significant differences between the BBS scores before (50.6 ± 4.9) and after (51 ± 5) HA use, with scores remaining within normal limits on both occasions.

Quality of Evidence

Table 3 shows the quality assessment of the ten studies reviewed. All studies were graded as “Fair” except for McDaniel et al. (2018) and Ninomiya et al. (2021), which were graded as “Poor”. All studies returned higher scores for quality of reporting than for external and internal validity. Statistical power was not reported in any of the studies.

Problems with both external and internal validity were noted for all studies. Problems with the external validity of most of the included articles were related to the lack of

representativeness of samples to the general population; no studies reported how the samples were selected, nor did they report sample proportions relative to the source population. Problems with internal validity were related to selection bias resulting from the absence of control groups, lack of blinding of participants and assessors, poor control for confounding variables (e.g., HA features, use duration and objective measures of gain, participants’ age, and aetiologies and types of HI) and finally the lack of inclusion of participants with balance problems.

Discussion

The findings of this systematic review indicate that for adults with HI, the evidence is equivocal that amplification with HAs improves static and dynamic balance compared to no amplification or to an unaided control group. Of the seven studies that measured static balance, six reported improvements (Ibrahim et al., 2019; Maheu et al., 2019; Negahban et al., 2017; Ninomiya et al., 2021; Rumalla et al., 2015; Vitkovic et al., 2016) and one reported no change in balance (McDaniel et al., 2018) with HA use. Of the two studies that measured dynamic balance, both reported no change in balance with HA use (Kowalewski et al., 2018; Weaver et al., 2017). The one study that measured both dynamic and static balance (Lacerda et al., 2012) reported no improvements when HAs were used.

Before discussing the potential effects of HAs on static versus dynamic balance, the eight limitations common to most of the studies reviewed must be noted. These limitations were: 1) the poor to fair quality ratings with 9/10 studies being single group case series lacking the control groups needed to attribute changes in balance to hearing aid use (some of these studies include control groups that could not be used to attribute changes in balance to hearing aid use, e.g., the use of control groups consisting of adults with normal hearing thresholds); 2) the use of participants with no self-reported or measured balance problems with 8/10 studies at risk of ceiling effects in their balance measures;

Table 3. Quality Measures of Individual Studies Assessed According to the Downs and Black (1998) checklist.

Study	Quality of reporting (Q1–10). Maximum = 11	External validity (Q11–13). Maximum = 3	Internal validity (Q14–26). Maximum = 13	Statistical power (Q27). Maximum = 1	Overall quality. Maximum = 28	Quality rating (Hooper et al., 2008)
Rumalla et al. (2015)	9	1	6	0	16	Fair
Ibrahim et al. (2019)	8	2	7	0	17	Fair
Negahban et al. (2017)	8	1	7	0	16	Fair
Maheu et al. (2019)	7	1	7	0	15	Fair
Ninomiya et al. (2021)	7	1	6	0	14	Poor
Vitkovic et al. (2016)	9	1	8	0	18	Fair
McDaniel et al. (2018)	6	1	5	0	12	Poor
Lacerda et al. (2012)	7	2	6	0	15	Fair
Weaver et al. (2017)	7	1	7	0	15	Fair
Kowalewski et al. (2018)	7	1	7	0	15	Fair

3) the lack of detail on HA type, fitting and usage, with some studies reporting laterality of fit, gain, and duration of use data but no studies reporting fitting algorithms, features or daily usage data; 4) the lack of detail on participant HI, which ranged from incomplete descriptions of type, degree and shape of HI to descriptions of hearing loss as simply being present or absent; 5) the variability in external sounds used, which ranged from no external sound to sounds of different acoustic and linguistic properties (e.g., stochastic noise versus sentences in multi-talker babble); 6) the small and variable sample sizes used in all studies; 7) the use of laboratory conditions in all studies rather than attempting to recreate real-world conditions where the participants would often need to maintain their balance; and 8) the variety of apparatus used (e.g., force platforms, Wii Balance Board) to complete a variety of clinical and laboratory measures of balance (e.g., sway area, velocity, time to overall balance).

Hearing Aids and Static Balance

The reported improvements in static balance with HAs (Ibrahim et al., 2019; Maheu et al., 2019; Negahban et al., 2017; Ninomiya et al., 2021; Rumalla et al., 2015; Vitkovic et al., 2016) were twofold. The first was an increased ability to maintain posture for longer periods in the presence of external sound (Ibrahim et al., 2019; Rumalla et al., 2015). The second was significant reductions in body sway area, velocity, or path length in both the anterior-posterior and/or mediolateral directions in the presence of external sound with HAs (Maheu et al., 2019; Ninomiya et al., 2021; Vitkovic et al., 2016) or in the absence of external sound with HAs (Negahban et al., 2017). These reports were countered by McDaniell et al. (2018) who reported no change in sway area when their participants wore HAs in the presence of external sound, and Lacerda et al. (2012) who found no change in five static balance measures in their participants before and after being fitted with HAs.

The improvements in static balance with HAs were most reported in the two conditions most assessed in the reviewed studies. The first condition was maintaining balance when standing on a foam surface (e.g., Romberg on foam and standing on foam with eyes open or eyes closed on the mCTSIB or similar test batteries), which is thought to particularly challenge somatosensory input. The second condition was placing one foot in front of the other (TST), which is thought to challenge balance by narrowing base of support and impairing lateral stability. In all but one of the occasions (Negahban et al., 2017) using these test conditions, the benefits of HAs were only observed in the presence of external noise and not in quiet. One interpretation of this result is the amplification of the external noise provided by the HAs allowed adults with HI to better access the spatial cues in the external sound that can help to orientate the body in space. A second interpretation extends the first by suggesting these additional auditory cues augmented the somatosensory

cues that had been compromised by the static balance task itself. Such augmentation could also be interpreted as a shift in the relative weightings given to the available cues when trying to maintain static balance. This shift could be to lessen the weighting given to somatosensory cues as they become less useful, to increasing the weighting given to auditory cues as they become more useful, for maintaining balance when standing on foam or placing one foot in front of the other. This second interpretation offers some support to Maheu et al.'s (2019) conclusion that HAs can decrease the reliance on somatosensory input for balance in adults with HI (although Maheu's finding was for participants with hearing and vestibular impairments and not HI only).

Hearing Aids and Dynamic Balance

The absence of improvements in dynamic balance with HAs in the three studies investigating dynamic balance in this review (Kowalewski et al., 2018; Lacerda et al., 2012; Weaver et al., 2017) was limited by the small number of studies and the diverse range of dynamic balance measures used. One interpretation of this result could be that in adults with HI, HAs do not benefit dynamic balance as measured by the BBS (Lacerda et al., 2012), gait (Weaver et al., 2017), or reactive balance (Kowalewski et al., 2018). Another interpretation could be that relative to other sensory inputs, hearing was not essential for maintaining dynamic balance in the tasks assessed in these studies. For example, the action of sitting-to-standing in the BBS would be more likely to depend on somatosensory, visual, and vestibular inputs than on auditory input, particularly considering most adults in the reviewed studies presented with no balance problems. More ecologically valid assessments of dynamic balance could be needed to detect any benefit of HAs on dynamic balance. Such assessments may need to depend more on auditory input for maintaining dynamic balance and may need to be applied to adults with both HI and balance problems before any potential benefit of HAs on dynamic balance can be fully determined.

Hearing Aids and Balance – General Discussion

A key challenge to investigating the effect of HAs on balance is the general nature of the terms “hearing impairment” and “balance”. HI can encompass a wide range of types, degrees, shapes, and causes, each affecting hearing differently in different adults. Similarly, balance is a complex process that comprises many systems (visual, somatosensory, and vestibular) with balance problems originating from one, some or all these systems even within a single adult. When choosing a research question in this field, it is critical to specify the nature of the HI, the HAs, the type of balance, and the balance impairment being investigated.

When considering HAs and balance, it also seems reasonable to expect that HAs would mostly benefit balance in adults with balance problems directly or indirectly related

to a coexisting HI. This emphasizes the need for appropriate research designs when attempting to isolate the effect of HA amplification on balance, including the use of appropriate comparisons or comparison groups where HA amplification is varied but the presence and type of balance problem is kept constant (or controlled for in an appropriate manner).

If hearing does contribute to balance, then research could benefit from identifying which impairments in which balance systems (visual, somatosensory and/or vestibular) are best managed by HA amplification. Research could also benefit from identifying which features in a HA maximize any benefits of amplification on balance. Examples could include the potential benefit of binaural HA fittings to maximize sound localization and noise suppression technologies to improve sound quality (although the latter would need to be implemented in a manner that doesn't interfere with the former).

The arguments offered above also identify the need to specify the details of the external sounds being amplified by the HAs during the HA and balance task. The use of white, pink, or narrow-band noises can offer consistency amongst research studies but can lack ecological validity. The use of linguistically loaded noise (such as BKB sentences) could increase the need for cognitive resources by creating a dual-task scenario where the listener must both maintain balance and understand the linguistic content of the sound (Kowalewski et al., 2018).

The current systematic review differs from the two previous systematic reviews (Borsetto et al., 2021 and Ernst et al., 2021) and one critical review (Carpenter and Campos (2020) in three of ways. First were differences in the included studies with Borsetto et al. (2021) reviewing eight studies and not reviewing three studies included in the present review (Ibrahim et al., 2019; Kowalewski et al., 2018; Ninomiya et al., 2021); Ernst et al. (2021) reviewing five studies and not reviewing five of the studies included in the present review (Ibrahim et al., 2019; Maheu et al., 2019; Kowalewski et al., 2018; Ninomiya et al., 2021; Vitkovic et al., 2016); and Carpenter and Campos (2020) using a different research design to address different aims to those addressed by the current review, which resulted in their review including only three studies investigating the effect of HAs on static balance (Maheu et al., 2019; Negahban et al., 2017; Vitkovic et al., 2016). Reasons for the differences in studies included between the present review and the three previously published reviews were difficult to determine due to differences in the use and reporting of inclusion/exclusion criteria. Second was the lack of explicit quality assessments of the included studies in the previous reviews, which was remedied by the present review's use of a validated quality assessment tool (Downs & Black, 1998). Third, was the less detailed descriptions of the studies in the previous reviews by Borsetto et al. (2021) and Ernst et al. (2021), which was remedied by the more detailed descriptions of the studies in the present review, particularly with regards to methods, balance measurements, acoustic environments, HI, and HAs.

Future Research

Future research into HAs and balance should address the methodological and conceptual limitations of the current evidence. Adequately powered, longitudinal Randomised Control Trial (RCT) designs should be considered to better elucidate and effects of HAs on both static and dynamic balance in adults with varying degrees, types and aetiologies of HI. The scale of such studies (and the resources required to conduct them) is noted and the use of high-quality observational studies should also be considered given their potential to provide evidence of an association (or not) between HAs and balance in adults with hearing loss. Issues regarding the external and internal validity of future studies should also be addressed via efforts to improve the degree to which sampled participants represent the target population, use of control groups and/or control conditions, blinding of participants and assessors, and control of confounding variables.

More ecologically valid trial settings should also be considered that better represent the real-world environments in which adults with HI regularly struggle with their balance. This could include using acoustical environments that resemble everyday listening situations rather than using white or filtered noise.

Future research should also consider the details of both the HAs and participant use of HAs such as HA type, monaural versus binaural fittings, insertion gain settings, programming algorithms, time since fitting, and daily use to name but a few. This call for greater detail could be premature, however, given the ongoing need to confirm if amplification via HAs can improve balance in adults with hearing loss, and if so, what mechanisms underpin any associations and do those mechanisms differ for static versus dynamic balance.

Lastly, and perhaps most importantly, is the pressing need to investigate the effect of amplification provided by HAs on the balance of adults with a wide range of self-reported and measured balance problems. Any benefit of HAs on balance is most likely to be realized in adults with hearing and balance impairments rather than HI alone.

Methodological Limitations and Strengths of the Current Review

This systematic review was limited to papers published in the English language in peer-reviewed journals only. The application of the search strategy and inclusion criteria identified only ten papers for inclusion, although the authors were confident that these 10 papers represented all the current research addressing the question asked in the current review.

Conclusion

For adults with HI, the evidence is equivocal that amplification with HAs improves static and dynamic balance compared to no amplification or to an unaided control group. Of the 10 studies

reviewed, six reported significant improvements in balance with HA use and four reported no improvements in balance with HA use, and all studies were limited by their fair to poor quality. Future research into the potential effects of HAs on balance in adults with HI should focus on adequately powered, longitudinal designs that use ecologically valid methods to better elucidate the effects of HAs on both static and dynamic balance in adults with hearing and balance impairment.

List of Abbreviations

ABC scale	Activities-specific Balance Confidence scale
AC	Air Conduction
AP	Anterior Posterior
BBN	Broad Band Noise
BBS	Berg Balance Scale
BKB-SIN	Bamford Kowal-Bench Speech-in-Noise test
CoP	Centre of Pressure
dB	Decibel
FES-I	Falls Efficacy Scale-International
HA	Hearing Aid
HI	Hearing Impairment
ITC	In the Canal
ITE	In the Ear
KHz	Kilo Hertz
m	meter
mCTSIB	modified Clinical Test of Sensory Interaction in Balance
ML	Mediolateral
N	Number
PICO	Population, Intervention, Comparison and Outcome
RoF	Romberg on Foam
PROSPERO	International Prospective Register of Systematic Reviews
PRISMA-P	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomised Control Trial
s	seconds
SD	Standard Deviation
SPL	Sound Pressure Level
SOT	Sensory Organization Test
SNHL	Sensorineural Hearing Loss
RITE	Receiver In the ear
TST	Tandem Stance Test
TUG	Time Up and Go
WN	White Noise.

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Supplemental Material

Supplemental material for this article is available online.

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