Literature Review: Auditory Contributions to Postural Steadiness in Older Adults With and Without Hearing Loss

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Balance is maintained by a complex process that integrates sensory information from the visual, proprioceptive, and vestibular systems in order to limit postural sway.[1] As these systems begin to deteriorate naturally with age, deficits in balance can develop that increase susceptibility to falls and limit the functional independence of community-dwelling older adults. Falls occur in over 25% of adults aged 65 years and older and can cause a wide range of adverse outcomes, including bone fractures, head injuries, increased healthcare costs, increased risk of recurrent falls, and even falls-related fatalities.[2] As a result of this, many older adults develop a fear of falling that further increases their risk of sustaining another fall.[2] As falls-related deaths in this population continues to rise in the United States,[3] it is important to continue research that identifies and mitigates risk factors for falls in older adults so that health professionals are able to provide comprehensive falls risk assessments and appropriate interventions. There is preliminary evidence that explores the association with hearing loss in older adults and increased risk of falls and suggests that the auditory system plays a role in sustaining balance; and thus, proposes hearing impairment as a potential falls risk to begin to consider.[4] This paper aims to review this existing literature to identify the relationship between hearing loss and falls risk, investigate the impact of hearing aid use and balance performance, and explain potential mechanisms behind auditory contributions to postural steadiness in community-dwelling older adults with and without hearing loss.

Hearing Impairment and Falls Risk

In community-dwelling older adults, hearing impairment is associated with a higher incidence of falls, increased risk of recurrent falls, and reduced postural stability.[5–7] Furthermore, these outcomes are often influenced by the individual's severity of hearing impairment. Hearing loss can be formally evaluated with audiometric testing, a gold standard that reports a pure-tone average (PTA) describing the measured hearing threshold (in decibel hearing loss, dBHL) at a given sound frequency (Hz).[8] The National Institute on Deafness and Other Communication Disorders (NIDCD) describes *normal* PTA at 25dB HL or less, *functionally hearing impaired* at 40dB HL, and *severely impaired* if greater than 70dB HL.[8] However, research shows that for every 10dB of hearing loss, the odds of sustaining an annual fall increase by 3.8%,[7] placing older adults with hearing impairment above 25dB at a 1.4-times increased risk of falls compared to those with superior hearing acuity.[4] A prospective cohort study by Kamil et al reported a significant association of increased odds of falling each year in older adults with *moderate-or-greater* hearing loss (9.7% at 95% CI) compared to older adults with *normal hearing* (4.4% at 95% CI).[7] This study included 2,000 community dwelling older adults between 70 and 79 years old who were independent in activities of daily living (ADLs e.g. eating, bathing, etc.), able to climb ten steps without resting, could complete a quarter-mile without difficulty, and did not exhibit any cognitive impairments.[7] The data was obtained from a larger prospective observational study that aimed to examine the association of both frailty and falls in individuals with and without hearing loss.[7] Audiometric assessments were administered in the 5th year of the study and falls history was assessed within the annual questionnaire.[7] At the conclusion of the 10-year prospective study, incidence of total falls occurrence for individuals with normal hearing, mild hearing impairment, and moderate-or-greater hearing impairments was 72.7%, 82.4%, and 81.1%, respectively.[7] Although this study suggests an association between hearing impairment and risk of falls, it is limited by its exclusion of any objective measurements of falls risk and its sole reliance on the participant's memory and willingness to accurately report their history of falls.

A study by Viljanen et al similarly reported an increased association between severity of hearing impairment and incidence of single falls in older female twins within a 12-month period.[9] This prospective cohort study examined 217 female twin pairs (both monozygotic and dizygotic) between the ages of 63 and 76 years old as a part of a larger twin study.[9] Of the participants included in the study, 10% reported being physically active, 9% reported ambulation difficulties, 19% sustained a fall within the past year, and 2% reported hearing aid use.[9] The investigators categorized hearing impairment as greater than or equal to the reported average of 21dB, which is considered mild hearing impairment.[9] When categorizing the women into four quartiles by hearing acuity, at least one fall occurred in 43%, 49%, 45%, and 53% in the best (acuity better than 11.5dB), second (11.5 to 17.5 dB), third (18 to 27dB), and worst quartile (above 27dB), respectively.[9] Furthermore, hearing impairment can also increase the risk of recurrent falls, as two or more falls occurred in 17%, 18%, 23%, and 30% of the best, second, third, and worst quartiles, respectively.[9] This association between hearing impairment and recurrent falls was further supported in the data reported by Pluijm et al whom examined potential predictor variables for falls risk profiles.[5] Out of 1364 community dwelling older adults, 36.7% sustained 2 or more falls within a 6-month period, correlating to a 1.51 odds ratio and a 95% confidence interval of 1.18 to 1.94.[5] Almost 40 potential predictors were examined in this study, however, hearing impairment was excluded from the final recommended risk profile.[5]

Outside of hearing severity, gender may also have a confounding influence on falls.[7] Based on the results by Kamil et al, the odds of falling was significantly greater in older women compared to older men in the study.[7] For example, the falls incidence of older women was 11.6% in the *moderate-or-greater* hearing loss group versus 3.5% in those with *normal hearing.*[7] Contrastingly, 8.5% of older men with *moderate-or-greater* hearing impairment sustained a fall versus 6.4% of those with *normal hearing*.[7] The researchers speculate that this may be a result of an increased likelihood to report a fall, an increased likelihood of sustaining a falls-related injury, and/or an increased likelihood of experiencing functional decline after a fall among older women compared to older men.[7]

Hearing Impairment and Postural Steadiness

Evidence suggests that older adults with hearing impairments demonstrate reduced postural stability compared to those without substantial hearing loss, providing one explanation for the increased risk of falls. Postural steadiness can be described as "the dynamics of the postural control system associated with maintaining balance during quiet standing"[10] or more simply described as the ability to maintain an upright position. Postural steadiness, often referred to as static balance, can be measured through maximum performance of a variety of standing positions or more precisely and quantitively measured through the use of force platforms.[10] The Viljanen et al twin study examined postural steadiness in older women through the maximal performance of semi-tandem stance, described as feet together with one foot halfway in front of the other, on a force platform.[9] As the position is held, the force platform measures the amount of sway or displacement of center of pressure (COP), which can be described by multiple parameters, such as COP *displacement* (total path length) and *mean velocity* (speed).[10] In this study, the COP displacement and mean velocity were significantly higher in older women greater severity of hearing loss compared to the older women with greater hearing acuity.[9] The COP mean velocity moments were 40.7 (24.4 SD), 46.3 (25.5SD), 50.6 (33.4 SD), and 58.2 (32 SD) mm^2/s for the best, second, third, and worst hearing quartiles, respectively.[9] Furthermore, there was a reported p-value of 0.003 for the trend in COP velocity by hearing quartile.[9]

Hearing Aid Influence on Balance

Consistent with these findings, there is limited low-quality evidence that demonstrates significant improvements in static postural steadiness in older adults with hearing loss when using bilateral hearing aids. Rumalla et al investigated the effect of hearing aid use on postural stability in 14 older adults with hearing loss of 25dB or worse and at least 3 months of bilateral hearing aid use.[11] Statistically significant differences in balance performance were reported in *aided* (hearing aids on) compared to *unaided* (hearing aids off) conditions.[11] Postural stability was assessed by the participants' ability to maintain balance for a maximum of 30 seconds in the Romberg stance position (with feet together) on foam and tandem stance position (with one foot directly in front of the other) on a hard surface.[11] Each subject completed both tests with and without hearing aids.[11] Statistical differences were found in both Romberg (P= 0.0051) and Tandem stance (P=0.0052) testing positions when comparing aided and unaided conditions.[11] The reported mean score for the more challenging tandem stance balance test was 4.5 ± 3.3 seconds without hearing aids compared to 9.8 ± 7.7.4 seconds with hearing aids.[11] However, the correlation between mean improvement on the two static balance tests and "gain with hearing aid use" were not detectable, reporting a Spearmen's rho of -0.115 and 0.400 and a P value of 0.751 and 0.600 for the Romberg and tandem stance, respectively.[11] Contrastingly, the four subjects that achieved maximum performance of the Romberg on Foam test in both aided and unaided conditions had a mean audiometric gain of 13.9 dB SPL compared to a 9.8 dB SPL average for the remaining 10 subjects, suggesting again that impairment severity may have some influence balance performance.[11]

Despite the results, none of the participants perceived improvements in balance when using the hearing aids prior to nor during the experiment, which demonstrates how subjective assessments of balance may not reflect the objective results.[11] When reviewing this study, it is important to consider its limitations, which include the ceiling effects and subjective evaluation of the selected static balance test, the small sample size, and the decreased external validity. The results of the study could have been more generalizable by including the quantitative Activities Specific Balance Confidence (ABC) scale scores, any existing comorbidities of the participants, and the duration of hearing aid use.

A similar study by Negahban et al also examined the effect of hearing aid use on static balance by comparing two groups of older adults (total of 47 subjects) aged 60 years or older with a hearing threshold between 40dB and 70dB.[12] The *aided* group had at least 3 months of bilateral hearing aid use and were assessed twice—once with their hearing aids on (on-aided) and again with hearing aids off (off-aided).[12] The *unaided* group did not have a prior history of hearing aid use and performed the balance tests only once in an unaided condition.[12] In this study, static balance was objectively assessed with force platform posturography in the Romberg stance position in four different combinations of a rigid surface versus foam surface and eyes open versus closed.[12] Negahban et al compared COP parameters between both groups, which included mean velocity, anteroposterior (AP) and mediolateral (ML) standard deviation (SD) velocity, and sway area.[12] The reported AP and ML SD velocities were significantly greater in the *off-aided* versus *on-aided* ($p<0.0001$) groups and the *un-aided* versus *on-aided* ($p<0.001$) groups of older adults, showing decreased postural stability without hearing aid use.[12] Additionally, a significant positive correlation ($r= 0.50$, $p= 0.017$) was reported between the time of hearing aid acquisition and the difference between aided/unaided conditions for AP SD velocity.[12] This suggests that individuals with longer use of hearing aids will see greater changes in AP postural stability with their hearing aids on versus off when compared to those who have used hearing aids for a shorter duration.[12] Although this study provides a larger sample size and more objective assessment of static balance, it is still limited by reduced generalizability by excluding data regarding falls history, balance deficits, or prevalence of vestibular conditions for the study participants. Furthermore, fatigue and/or learning effects may have confounded results of the hearing aid group who were assessed twice without counterbalance.

Contrasting results were found by McDaniel et al when using Sensory Organized Testing (SOT) as the outcome measure for static balance, reporting no significant differences in balance in 22 older adults (58 to 81 years old) with hearing aids on versus off.[13] SOT is a form of computerized posturography that evaluates the complex system of balance by manipulating the visual, proprioceptive, and vestibular senses through isolation of varying sensory modalities.[13] Each participant underwent six testing conditions of the SOT—1) quiet stance and eyes open, 2) quiet stance and eyes closed 3) quiet stance, eyes open, and the SOT box moving with the participant as they sway.[13] The remaining conditions repeat the first three, with the addition of an unlocked force plate that moves with the sway of the participant, thus, providing incorrect proprioceptive input.[13] All participants were first tested with hearing aids on then repeated after five minutes without their hearing aids.[13] A paired-*t* test for the aided and unaided positions was performed for the aided and unaided conditions and then a repeated measures analysis was conducted for each condition.[13] No significant differences were found between the aided and unaided conditions for the SOT composite score nor between or among variables for the six conditions.[13] However, the inconsistency of these results compared to other studies may be a result of learning effects as demonstrated in evidence when assessing SOT performance in older adults[14] and/or the difference in type of balance outcome measure utilized. Furthermore, this study may be limited by the ceiling effects of the SOT test, small sample size, insufficient power, and gender imbalance. Since evidence suggests that older women with hearing loss have increased odds of falling compared to men,[7] then the study should have included more than 3 out of 22 female participants.

Impact of Hearing Impairment on Older Adults

One systematic review further investigated the relationship of hearing loss and postural control in community-dwelling older adults. Agmon et al reviewed seven studies which all reported a significant positive association between hearing, balance, and postural stability based on objective measurements of standing balance and/or postural sway.[4] The review categorized outcome measures for assessing postural control into "three main methodologies: subjective assessment by examinations, objective assessment by scale-based tests, and quantitative measures by means of force platforms"[4] In addition to assessing postural steadiness, the studies included in this review also evaluated additional outcomes such as gait speed, functional tests (such as chair stands), walking endurance and distance, perceived mobility and self-reported physical activity levels.[4] The findings revealed that hearing impairment was associated with decreased physical function, impaired perceived walking ability, social isolation, decreased community participation, depression, cognitive impairments, and increased risk of falls.[4] There is also existing evidence that the presence of auditory biofeedback can decrease postural sway (and thus increasing postural steadiness) and that balance performance can improve with hearing aid use (for individuals with impaired hearing).[4] Moreover, the severity of hearing impairment was positively associated with increased prevalence of falls and walking complications in this population.[4] In efforts to explain this connection, researchers propose that auditory biofeedback increases direction of attention and/or provides an orienting reference to reduce postural sway and improve postural stability.[4] However, future research is needed to further examine the potential mechanisms of the auditory contribution to balance.[4]

Proposed Mechanisms in Literature

Potential explanations for the relationship between hearing impairment and postural stability currently proposed in literature can be categorized into physiological, cognitive, and behavioral mechanisms.[4] Age-related physiologic changes, such as neural degeneration and shared inner-ear impairment, can simultaneously affect the vestibular structures and cochlea, and therefore impair balance and hearing, respectively, due to their close proximity.[4,15] Furthermore, changes in the corpus callosum, which is a bundle of nerve fibers responsible for integrating sensory, motive, and cognitive functions,[16] can present concurrently with neural presbycusis (described as atrophy to the brain's auditory pathways and nerves within the cochlea as a result of aging) and impair one's walking ability.[4] Similarly, microvascular diseases that occur over time with age may negatively affect both the cochlea and lower-extremity performance.[4] These are all examples of physiological mechanisms that can explain the association between impairments in hearing and postural stability. However, the effect of genetics on postural stability was found to be not significant.[9]

Proposed cognitive mechanisms associated with hearing loss and reduced postural stability include reduced executive functioning (responsible for planning and focusing attention) and impaired divided attention abilities.[4] However, this more commonly affects dynamic balance activities, such as walking.[4] Since dynamic balance requires a more sensitive "equilibrium between automatic and executive control," the cognitive decline associated with aging causes a reduced ability to automatically perform movements and a stronger need to rely on these executive resources.[4] Depending on the type of auditory stimuli present, older adults may require more attention to the perception of the stimuli and to processing this information, thus reducing the quality of mobility and ambulation.[4]

The last category of behavioral mechanisms is described as the *consequences* resulting from hearing impairment, which include social isolation, reduced physical activity, and reduced spatial awareness.[4] As hearing deteriorates with age, older adults lose their ability to adequately detect and perceive auditory stimuli, which creates uncertainty in orientation to the environment.[4] As a result, older adults find themselves in more hazardous situations and more susceptible to falls.[4] This consequently often leads to further limitations in mobility, decreased confidence in physical activities, and increased social isolation.[4] However, evidence suggests that the use of hearing aids in community-dwelling older adults with hearing loss can reduce community-related mobility dysfunction and loneliness.[4] Although these consequences contribute to increased risk of falls, it does not explain how auditory input can directly contribute to the reduced postural stability resulting in falls.

Spatial localization is a mechanism commonly suggested by researchers to explain the direct auditory contributions to balance.[4,7,11,12,17,18] Auditory input establishes a point sound source that provides biofeedback for spatial orientation.[11,12] By localizing the sound sources, the brain develops a three-dimensional map as a "reference" in order to maintain postural steadiness in relation to these external landmarks.[11,12] A study by Vitkovic et al explored whether an auditory map is used to control balance by manipulating auditory cues under various balance conditions in 50 adults with normal hearing (21 to 56 years old), 28 adults with hearing impairment (26 to 80 years old, only 19 used hearing aids), and 19 adults with vestibular dysfunction (33 to 83 years old).[17] Each participant underwent four standing balance conditions (firm surface with eyes open, firm surface with eyes closed, foam surface with eyes open, and foam surface with eyes closed) while standing with feet apart for 60 seconds, and their postural stability was measured under four sound conditions—ambient, no sound (ear plugs), continuous white noise, and moving noise.[17] Although this study was not exclusive to older adults, the young to middle-aged normal hearing adults yielded higher COP total path lengths in the absence of sound, demonstrating increased postural sway in the absence of auditory cues.[17] The hearing impaired demonstrated decreased postural sway with hearing aid use with auditory cues and slight increase in sway with auditory cues without hearing aid use, but these results were not statistically significant.[17] Many researchers have proposed this mechanism as a potential cause of reduced postural stability in community-dwelling older adults, but there is a gap in literature that provides high-level evidence specifically aimed at manipulating auditory cues to investigate the effect of special localization in this population.

Implications for Future Research

This literature review explores low-quality evidence that demonstrates an association with hearing impairment and increased risk of falls, reduced postural stability, and improvements in static balance performance with hearing aid use in community-dwelling adults. However, higher quality evidence with adequate power and consistent methodology, in addition to more robust research investigating potential mechanisms is warranted. All of the studies vary in type of auditory stimuli, visual conditions, balance assessment, testing conditions, and participant characteristics, making it difficult to standardize and generalize the results. For example, auditory stimuli included ambient sound,[12,17] white noise,[11,17] multitasker babbles,[13] moving sound,[17] or no sound[17] and visual stimuli was inconsistently eliminated. The type of static balance test differed amongst studies, which included feet shoulder with apart,[13,17,19] Romberg stance (feet together),[11,12] semi-tandem stance,[9] and tandem stance,[11] while the type of surface also varied (i.e. foam, hard surface, or force platform). The measuring technique of balance ranged from maximum duration of sustained position (without falling or taking a step) to a more objective force platform posturography, which often led to variations in type of COP parameters reported. Furthermore, there were inconsistencies in the age range for older adults—McDaniel et al began the age range at 58 years old, Negahban et al at 60 years old, Viljanen et al at 63 years old, and Rumalla et al at 65 years old[6,11–13]—despite the commonly accepted definition in the U.S. of 65 years and older. Although this is not an exhaustive list of limitations of existing evidence, it demonstrates the need for additional research to determine if hearing impairments contribute to postural unsteadiness and thus, increasing risk of falls among community-dwelling older adults. Once there is sound, high quality evidence supporting the auditory contributions to balance, health professionals would be justified in considering and addressing hearing impairments when conducting falls assessments and developing interventions for this population.

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