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Auditory Input and Postural Control in Adults
A Narrative Review

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+ Supplemental content

IMPORTANCE An increase in the number of mechanistic studies targeting the association between sound and balance has been observed in recent years, but their results appear equivocal.

OBSERVATIONS A search of PubMed and the Cochrane Database of Systematic Reviews for English-language studies on auditory input and postural control published from database inception through October 31, 2019, yielded 28 articles for review. These articles included 18 (64%) studies of healthy adults, 1 (4%) of participants with Alzheimer disease, 2 (7%) of participants with congenital blindness, 3 (11%) of participants with vestibular loss, and 4 (14%) of participants with diverse levels of hearing loss. Studies varied by the type of audio stimuli (natural vs generated sounds), apparatus (speakers vs headphones), and movement of sounds (eg, stationary, rotational). Most balance measurements involved standing on the floor or foam with eyes open or closed during which sway amount or velocity was quantified. Stationary broadband sounds, including white or environmental noise, may improve balance, but the results regarding stationary pure tone were inconclusive. The implication of moving sounds varied by apparatus (typically destabilizing when headphones were used) and sensory loss (more destabilizing with vestibular or hearing loss but perhaps less with a unilateral cochlear implant).

CONCLUSIONS AND RELEVANCE Findings from this review suggest that stationary broadband noise can serve as an auditory anchor for balance primarily when projected via speakers and when the balance task is challenging. More research is needed that includes individuals with sensory loss and that tests paradigms using dynamic, ecologically valid sounds; clinicians should also consider auditory cues and the presence of hearing loss in balance and fall-risk assessments.

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Falls are the leading cause of fatal injuries in the United States, and they have important implications for quality of life.[1] Previous studies have suggested that hearing loss is associated with reduced balance performance in adults[2] with[3] or without dizziness and could be a potentially modifiable risk factor for falls.[4,5] Decreasing fall risk in individuals with hearing loss requires a better understanding of the mechanism underlying this association. Liu et al[6] proposed that the association between hearing loss and balance problems may be mediated by an underlying subthreshold vestibular dysfunction even without vestibular symptoms. Other studies have suggested that auditory cues are needed for environmental awareness and that individuals with hearing loss develop substitution strategies,[7,8] in which individuals depend on other sensory input (vision, vestibular, or somatosensory) or cognitive resources to maintain their balance.[9]

Do auditory cues participate in the sensory integration process for postural control? In recent years, we have observed an increase in the number of mechanistic studies attempting to explain a possible independent association between sounds and postural control. Studies in this area spread across diverse research fields, including acoustics and psychoacoustics, audiology, otology and neurotology, movement sciences, psychology, and physical therapy. In this narrative review, we (1) define the terms used to describe the auditory aspects of postural control and sound paradigms, (2) describe the method used to study the association between auditory input and postural control, (3) summarize the findings regarding the implications of auditory input for standing postural control in healthy adults and individuals with sensory loss (such as vestibular or hearing loss), (4) propose a mechanism by which auditory cues are used for balance, and (5) provide recommendations for future research.

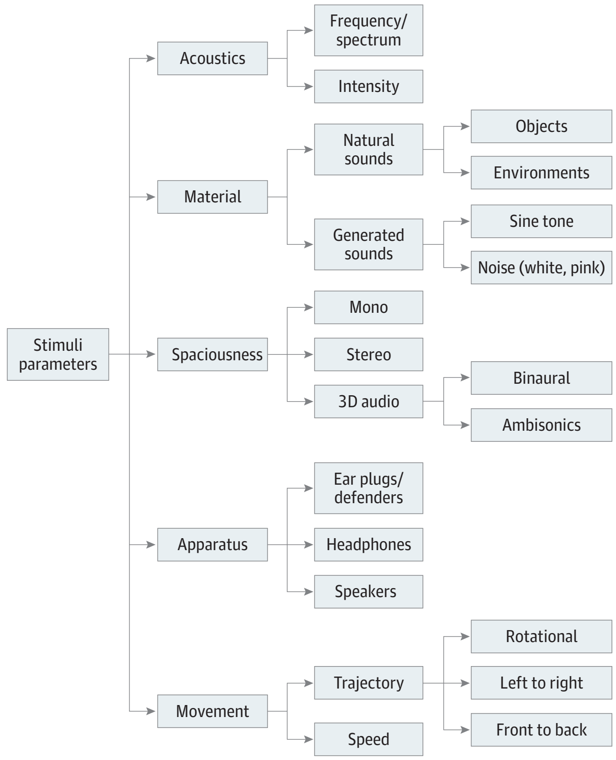
Methods

We searched PubMed and the Cochrane Database of Systematic Reviews for English-language studies published from database inception through October 31, 2019; the search strategy is outlined in eAppendix 1 in the Supplement. We also manually searched the bibliography lists of all included articles. Eligible studies included adults (aged 18 years or older) and tested the association of auditory perturbations with standing balance. We excluded studies that tested dynamic tasks (eg, stepping or gait), had training components, or used sounds as biofeedback or dual task.

We could not include several other auditory paradigms that appeared in the literature, such as the implication of groove, timbre, or reverberation because each was studied in only 1 article. We also excluded studies that investigated responses to music because moving with music may be associated with affect or emotional expression, and this psychological urge to move may confound the results.

To create a common language with which to discuss the disparate experimental paradigms related to sound and posture, we defined terms describing sound stimuli, hardware, and paradigms (eAppendix 2 in the Supplement).[10-12] Balance paradigms and outcomes were also defined (eAppendix 3 in the Supplement). The **Figure** provides a conceptual framework of auditory stimuli variables used in previous research.

Figure. Overall Framework of Auditory Paradigms and Stimuli Parameters



Observations

In total, we reviewed 28 articles. These articles included 18 (64%) studies involving healthy adults, 1 (4%) had participants with Alzheimer disease, 2 (7%) included participants with congenital blindness, 3 (11%) involved participants with vestibular loss, and 4 (14%) had participants with diverse levels of hearing loss.

Healthy Adults

Results from the healthy adult population are summarized by auditory paradigm in **Table 1**. Reduction, no difference, and increase in sway were all observed with sound attenuation.[13-15] A fixed, nonmoving broadband noise (white or pink) was consistently found to reduce sway.[16-21] The more sway the participants had originally, the more sway reduction they experienced.[16]

The results regarding pure tone or narrowband static sound were inconclusive.[22-27] Static prerecorded natural sounds appeared to reduce postural sway. Gandemer et al[28] concluded that the richer the auditory environment, the more individuals can integrate sound information to decrease their postural sway. Sounds moving front to back or side to side were found to increase sway.[29] Sounds moving along a 180-degree arc were found to increase sway (compared with silence) in 1 study[30] but to reduce sway (compared with blocking sounds) in another study.[13] Other studies reported reduction, no change, or increase in postural sway with rotating sounds.[31-35] Guigou et al[35] postulated that, in monaural hearing, the rotation of the sound was not perceived, and thus sound had a stabilizing role like a stationary sound.

Table 1 lists other studies on frequency modulation[36,37] or unpleasant sounds.[38] In healthy adults, several studies found no association between sound loudness[27,39,40] or sound pressure level[36] and postural sway. Siedlecka et al[27] found that sway area was reduced with extreme loudness only in high-frequency trials.

Hearing Loss and Vestibular Dysfunction

Four studies included individuals with diverse levels of hearing loss[13,19,35,41] (**Table 2**). Three of the 4 studies suggested that sounds may be used to improve balance in individuals with hearing loss if the participants can hear the sounds.

Three studies included adults with various levels of vestibular dysfunction.[13,19,35] All 3 studies found that the associations of sounds with postural control (ie, stabilizing with static sounds or destabilizing with moving or blocked sounds) were magnified in adults with vestibular dysfunction. It appeared that adults with vestibular dysfunction may use an auditory substitution strategy[42,43] similar to that seen with visual and somatosensory substitution. The change was larger in individuals with unilateral vestibular dysfunction than in healthy adults (Table 1).[13]

Congenital Blindness and Alzheimer Disease

Single-frequency sounds were used in 2 studies that compared postural control in individuals with congenital blindness and control participants.[22,25] Both studies reported that auditory cues can be used to improve postural control in individuals with congenital blindness. No significant reduction was observed with 1 speaker placed in front of participants' heads or with a head-mounted sonar.[22]

One study showed that suppressing background noise was beneficial for postural control in individuals with Alzheimer disease.[26] Gago et al[26] concluded that audition, although less important than vision, also played a role in the process of multisensory integration for postural control by the central nervous system. Although the results were similar in individuals with Alzheimer disease and in control participants, this finding could be particularly important for patients with Alzheimer disease who may substitute for cognitive decline by sensory dependence.

Table 1. Auditory Contributions to Postural Control in Healthy Adults

Source (Cohort Size)	Balance Test Condition and/or Auditory Paradigm	Main Result	Take-Home Message
Sound Attenuation via Earplugs			
Vitkovic et al,[13] 2016 (N = 50)	Floor and/or foam with eyes open or closed	Increased sway when blocking sounds	Silence had an adverse effect on balance if the testing condition was challenging enough (eg, standing on foam). This adverse change was minimal in healthy adults compared with an eyes closed condition.
Kanegaonkar et al,[14] 2012 (N = 20)	Floor and/or foam with eyes open or closed	Increased sway when blocking sounds	
Ambrosio et al,[15] 2017 (N = 19)	Staggered stance with eyes open	No difference	
Stationary Sounds			
Broadband noise			
Stevens et al,[16] 2016 (n = 12 healthy; n = 6 balance problems)	Eyes open or closed	White noise projected simultaneously from 4 speakers positioned around the participant associated with reduced velocity of sway compared with no sounds and eyes closed only	A fixed, nonmoving broadband noise (white or pink) has consistently been shown to reduce sway.
Zhong and Yost et al,[17] 2013 (N = 19)	Tandem position with eyes closed	Small but substantial reduction in head sway with broadband white noise via speakers	
Maheu et al,[18] 2017; 2019[19] (N = 14 in each study)	Floor and/or foam with eyes open or closed	The difference in postural sway between eyes closed and eyes open conditions (visual reliance) greater when participants had hearing protection and could not hear a stationary pink noise	
Ross and Balasubramaniam et al,[20] 2015; Ross et al,[21] 2016 (n = 19, or n = 15 young and 15 older)	Eyes open or closed	A small but substantial reduction of sway with white noise via headphones in young adults and in young and older adults, regardless of the visual condition (eyes open or closed)	
Narrowband noise/pure tones			
Easton et al,[22] 1998 (N = 10)	Tandem position with eyes open or closed	A substantial reduction in postural sway when a stationary 500 Hz sound wave was projected via 2 speakers (1 on either side of the head at ear level), compared with no sounds	The results of narrowband noise and/or tone in healthy adults were inconclusive.
Raper and Soames,[23] 1991 (N = 30)	Eyes open or closed; sounds projected front, behind, right, or left of the participants via speakers placed 0.5 m from the participants at their height	A substantial increase in postural sway with pure tone of 250 Hz, compared with silence, independent of vision	
Mainenti et al,[24] 2007 (2 experiments: n = 36; n = 30)	Eyes open or close; sounds projected via telephonic earphones	No difference in sway with pure tone of 500 Hz or 4000 Hz or intermittent clicks on 1 side, compared with no sounds	
Sioud et al,[25] 2019 (N = 11)	Double leg or single leg with eyes open; loudspeaker placed 2 m behind the participant at 1.2 m height	No difference in sway with an alarm beep at 1000 Hz	
Gago et al,[26] 2015 (N = 24)	Normal stance	Increased sway with background noise at 125-2000 Hz, compared with blocking the noise with ear defenders	
Siedlecka et al,[27] 2015 (N = 29)	Normal stance. Pure tone or instrumental sounds (eg, guitar, piano) projected via headphones	Reduction of sway with sounds of 1000 Hz or 4000 Hz, compared with no sounds; no difference with 225 Hz	
Prerecorded natural sounds			
Raper and Soames et al,[23] 1991 (N = 30)	Eyes open or closed; sounds projected either front, behind, right or left of the participants via speakers placed 0.5 m from the participants at their height	No difference in sway between silence and general background conversation	Static rich auditory environment of more than 1 source may reduce sway.
Gandemer et al,[28] 2017 (N = 35)	Feet together, floor and/or foam, blindfolded; semi-real listening environment was used: resynthesized ecologically valid sounds (eg, water fountain) using ambisonics	A consistent decrease of sway as sound sources were added from 3 to 10 isolated sources (eg, fountain sound, motor sound); the decrease in sway greater in a rich immersive environment compared with an isolated source; 15% maximal decrease in sway, compared with a no-sounds condition	
Moving Sounds			
Front to back or left to right			
Soames and Raper et al,[29] 1992 (N = 30)	Eyes open or closed; sounds moved between speakers from side to side or front to back at a frequency of 0.1 Hz	More sway with moving sounds (pure tone of 250 Hz) or general background conversation, compared with silence	One study suggested reduced sway with moving sounds compared to completely blocking sounds.

(continued)

Table 1. Auditory Contributions to Postural Control in Healthy Adults (continued)

Source (Cohort Size)	Balance Test Condition and/or Auditory Paradigm	Main Result	Take-Home Message
180° Arc			
Agaevea and Altman,[30] 2005 (N = 5)	Normal stance; sounds moved in the sagittal plane through an arc of 53 loudspeakers	Increased sway with moving sounds; participants tended to lean in the direction of the sounds, mostly on the longer trials (close to 5 s vs 3 or 2 s)	Two studies suggested increased sway with moving sounds compared with silence.
Vitkovic et al,[13] 2016 (N = 50)	Floor and/or foam with eyes open or closed; white noise moved in the frontal plane across a semicircular array of 8 speakers at a pace of 1 speaker per second	Reduced sway with moving sounds, compared with blocking sounds	
Rotating sounds			
Gandemer et al,[31] 2014; Gandemer et al,[32] 2016 (N = 20; the same cohort for both studies)	Feet together, floor, blindfolded; participant fully surrounded by 16 speakers, with the sound moving at 20°, 60°, or 180° per second	Reduced sway in the presence of rotating white noise, compared with 2 control conditions (no sound or stationary sound). The faster the sound source was rotating, the greater the reduction in body sway. The stabilizing role was only retained when participants were instructed to focus on the sound.	Inconclusive. Differences between studies could be explained by attention (whether participants were instructed to focus on the sounds or not); hardware (spatial auditory cues provided by speakers were maybe better than those of 3D headphones).
Deviterne et al,[33] 2005 (N = 32, older than 60 y)	Normal stance; sound rotating clockwise over 4 speakers at 0.2 cycles per second	No implication of rotating 440 Hz continuous tone for postural sway of older adults	
Tanaka et al,[34] 2001 (n = 6 young; n = 6 old)	Feet together, floor and/or foam with eyes open or closed; white noise projected via headphones and rotated clockwise or counterclockwise in an ellipse around them with a mean frequency of 64.4 frames per second	No difference in young adults; in older adults, sway increased when the sound was rotating and only with eyes closed or foam	
Guigo et al,[35] 2018 (N = 37)	Dynamic posturography, with cocktail party sounds projected via headphones and rotated at 189° per second	No implication of rotating cocktail party sounds, compared with no sounds	
Other			
Frequency of sound			
Park et al,[36] 2011 (N = 11)	Normal stance; tones projected via headphones; no silent condition for comparison	A small but substantial increase in sway when the frequency (pitch) of pure tone increased from 1000 Hz to 3000 or 4000 Hz	Participants tended to sway with sounds that had a beat.
Metronome			
Coste et al,[37] 2018 (N = 20)	Normal stance with gaze fixation on a target; metronome used that projected discrete pure tone beeps via headphones	Participants matched their body sway to the beat, particularly on the low frequencies of beat (0.25 Hz)	Participants tended to sway with sounds that had a beat.
Unpleasant sounds			
Chen and Qu et al,[38] 2017 (N = 24)	Eyes closed; sounds projected by 2 speakers	Stationary unpleasant sounds associated with more sway, compared with sounds classified as pleasant or compared with no sounds	Participants tended to sway with sounds that had a beat.
Loudness and/or intensity			
Park et al,[36] 2011 (N = 11)	Normal stance; tones projected via headphones	No substantial implication of the tone intensity level (45, 90, or 120 dB)	Loudness did not appear to be a factor in postural sway.
Polechonski and Blaszczyk et al,[39] 2006 (N = 80)	Eyes open or closed; white noise or applause projected at 60, 80, or 100 dB via stereophonic headphones	No substantial implication of sound loudness	
Sakellari and Soames et al,[40] 1996 (N = 8)	Feet together with eyes open or closed; loudspeakers at standard distance (40 cm) on either side of the participant at 125 cm below ear level	No substantial implication of sound loudness	
Siedlecka et al,[27] 2015 (N = 29)	Normal stance; pure tone or instrumental sounds (eg, guitar, piano) projected via headphones	Sway was reduced with extreme loudness only in the high- frequency trial	

Abbreviation: CI, cochlear implant.

Discussion

Suggested Mechanism of Auditory Input in Balance

The 28 studies included in this review were generally guided by the weighting and reweighting theory of sensory integration for postural control. This theory suggests that individuals prioritize sensory information differently on the basis of the sources of sensory input available and the challenge induced by the task.[44,45] It is well established that postural control requires ongoing integration of visual, vestibular, and somatosensory information, but the studies reviewed herein suggest that, overall, auditory input also has implications for postural sway in standing.[23] Nevertheless, auditory cues appear to have a minor association with postural control compared with

Table 2. Auditory Contributions to Postural Control in Clinical Populations

Source (Cohort Size)	Balance Test Condition and/or Auditory Paradigm	Main Result	Take-Home Message
Hearing Loss			
Guigou et al,[35] 2018 (n = 15 unilateral CI; n = 7 bilateral CI)	Dynamic posturography, with rotating cocktail party chatter via headphones	The presence of rotating cocktail party chatter via headphones reduced postural sway when participants with unilateral CI were standing with eyes closed, and increased postural sway in participants with bilateral CI.	3 of 4 studies (except Maheu et al[19]) suggested that sounds may be used to improve balance in individuals with hearing loss if they can hear the sounds.
Vitkovic et al,[13] 2016 (N = 9)	Floor and/or foam with eyes open or closed and earplugs	Participants with diverse types of hearing loss and no hearing aid were not affected by earplugs (their sway did not change), compared with no earplugs. When participants were wearing a hearing aid, they increased sway with earplugs.	
Maheu et al,[19] 2019 (N = 18)	Floor or foam with eyes open or closed and stationary pink noise via 1 speaker behind the participant. Participants counted backward, starting from 1000, to control for their focus of attention (not focused on the sounds).	Participants with hearing loss and no vestibular loss were not affected by removing their hearing aids such that they could not hear a stationary pink noise.	
Rumalla et al,[41] 2015 (N = 14)	Feet together on foam and/or tandem on the floor in darkness with white noise via 1 front speaker	10 of 14 participants with hearing loss were able to hold a static position longer when standing on foam with feet together with hearing aids, as compared with no hearing aids.	
Vestibular Loss			
Guigo et al,[35] 2018 (N = 10)	Dynamic posturography with rotating cocktail party chatter via headphones	Participants with bilateral vestibular loss and normal hearing increased their sway when standing with eyes closed and listening to rotating sounds (compared with silence) via headphones.	3 of 3 studies suggested that the association of sounds with postural control (stabilizing with static sounds or destabilizing with dynamic and/or blocked sounds) may be magnified in adults with vestibular dysfunction.
Vitkovic et al,[13] 2016 (N = 19)	Floor and/or foam with eyes open or closed and earplugs	Participants with unilateral vestibular dysfunction (with or without various degrees of hearing loss) substantially increased their sway with sounds blocked.	
Maheu et al,[19] 2019 (N = 10)	Floor and/or foam with eyes open or closed and stationary pink noise via 1 speaker behind the participant	Participants with hearing loss and vestibular dysfunction had increased sway without sounds when standing on foam (mostly with eyes closed). With hearing aids, participants were able to hear the pink noise provided. Under that condition, participants reduced their sway substantially on the challenging conditions (foam).	
Congenital Blindness			
Easton et al,[22] 1998 (N = 8)	Tandem position eyes open or closed with 500 Hz wave via 1 or 2 speakers	Substantial reduction in lateral postural sway for the 2-speaker condition only; for lateral head sway: more head sway in the blind for all conditions, reduction in head sway with the 2 speakers and the sonar conditions.	Balance control was impaired in individuals with congenital blindness compared with controls. Auditory cues can be used to improve postural control in individuals with congenital blindness.
Sioud et al,[25] 2019 (N = 11)	Double leg or single leg with eyes open, alarm beep at 1000 Hz, and 1 speaker behind the participant	With sounds in a double-leg position, participants who were blind increased their sway to a level that was comparable to controls; without, sounds had substantially less sway in participants who were blind.	
Alzheimer Disease			
Gago et al,[26] 2015 (N = 24)	Normal stance with ear defenders to block background noise	Blocking a specific background noise somewhat reduced sway in participants with Alzheimer disease standing with eyes open or closed for 30 s.	This study showed that suppressing noise was beneficial for postural control in individuals with Alzheimer disease.

Abbreviation: CI, cochlear implant.

visual, somatosensory, and vestibular information. In studies involving healthy control participants, the findings were variable (ie, increased, reduced, or no change in sway with different sounds). The role of auditory cues seems to become more important in the presence of inherent sensory loss (such as those with vestibular dysfunction or visual impairment) or paradigm-induced sensory loss (ie, standing on foam with eyes closed). The increase in sensory reliance was not seen for the change in somatosensory input (standing on floor and/or foam).[18,19] Discrepancies in studies with healthy young adults may reflect the inherent redundancy of a healthy system. In individuals with multiple possible strategies to generate a stable stance, auditory cues may not be essential for balancing during standing.

One proposed theory regarding the integration of sound into postural control is that of auditory anchorage.[28,35] According to this theory, stationary sound sources provide spatial information that helps the brain structure a spatial image of the environment. The brain then uses that information for stabilization. This concept has parallels in other research involving visual integration for balance. Previous research has consistently shown that a visual anchor decreases postural sway,[46] compared with no vision or a moving visual stimulus. The use of an auditory anchor is supported by studies demonstrating that stationary sound sources and addition of sound sources helped reduce sway,[16,22,28] whereas sound attenuation increased sway.[14] A stationary source of sound, however, does not guarantee reduction in sway. Reduced sway with stationary sounds has been reported for broadband noise (eg, white noise), but the studies were inconclusive regarding pure tones.[23] Compared with pure tones, broadband noise is richer (ie, combines all frequencies, has greater ecological validity and increased familiarity, or is more authentic and occurs in nature). In localization studies, participants typically localized white noise better than pure tones.[12] Any or all of these characteristics of the sound could allow it to function as an auditory landmark. In addition, stationary white noise was primarily tested via speakers. Karim et al[47] suggested that a stationary white noise source had to be earth-referenced rather than head-referenced (speakers rather than headphones) to improve performance on a dynamic task. Ross and Balasubramaniam,[20] however, observed some reduction of sway with white noise presented by headphones.

Overall, previous studies have suggested that healthy young adults are more likely to use auditory cues for balance in paradigms with reduced sensory input, such as standing with eyes closed or standing on a compliant surface. This finding was not the case with standing on foam among healthy young adults,[28] but foam was a factor in the integration of auditory cues in individuals with vestibular and hearing loss.[19] In addition, the combination of blocking vision and standing on foam increased the importance of sounds for balance in healthy older adults.[34] It is possible that the foam was not challenging enough to induce sensory reweighting in healthy young adults[48] compared with those with sensory loss.

The auditory landmark theory suggests that the sudden perturbation[30] or jumping from one side to the other[29] of the sound source will interfere with the hearing spatial map, leading to destabilization (ie, increased postural sway). However, this theory does not explain the reduction in sway associated with rotating sounds. It is possible that continuous, regular movement of sounds from an array of speakers can also be used to improve postural sway. Gandemer et al[31] proposed that the rotation provides additional sensory input to supply and enrich the spatial map. This process seemed to happen when auditory cues of white noise were projected from an array of speakers rather than headphones. Such a setup allows for localization of the sound using differences in the temporal and intensity characteristics of the sound. Another possibility is that participants reweighted the fast-rotating sounds and used the stable ground to reduce their sway. Studies with different setups such as headphones, however, did not observe the same phenomena.[35] Reduction in sway is not expected with moving visual stimuli or support surfaces. Peterka[44] found that increased sway in healthy adults was associated with an increase in the amplitude of the visual and surface movements until those movements were too large to follow and thus no longer induced an increased sway. This behavior coincided with reweighting of unreliable sensory cues. Even in the case of such normal reweighting, however, the overall amount of sway with a moving visual stimulus or surface was higher than that of the static conditions. Therefore, the possibility that rotating sounds can facilitate stability suggests a different mechanism for sounds vs vision integration for postural control. This possibility needs to be further studied within naturally moving sounds, such as a train or a bus, combined with visual cues that are static or dynamic.

An alternative theory for the association of sound with posture pertains to the role of attention in sensory integration for balance. In addition to the array of speakers and broadband sounds that could provide spatial cues, the study by Gandemer et al[31] also involved a cognitive task that was compatible with the movement of the sounds; participants were asked to count the number of laps the sound completed. It is possible that the cognitive load through the secondary task was associated with reduced sway and not the auditory input by itself. Supporting the importance of attention, other studies in healthy adults suggested that sounds can be integrated only if they are attended to, a claim that is not typically made for visual, somatosensory, and vestibular information. The reason may be that the association between sounds and postural control is weaker than that between visual, somatosensory, and vestibular when all sensory systems are intact. This possibility has led several authors[28,33] to propose that the reduction in sway is attributable to the concurrent cognitive task rather than the sounds themselves. Future studies should test this theory within challenging balance tasks and among individuals with sensory loss for whom the ability to switch focus of attention may be more limited.

Directions for Future Research

Study Populations

Future study populations should include individuals with sensory loss. Inclusion criteria should be well defined and cohesive in terms of the degree of hearing loss, vestibular loss, or a combination, such that a comparison between normal aging and aging with sensory loss can be made. When the role of sound in posture among people with specific levels of hearing loss has been clarified, studies should assess whether hearing rehabilitative strategies (ie, hearing aids, cochlear implants) can change sensory integration and thereby affect balance performance.

Auditory Paradigm

Future studies should include prerecorded sounds of real-life situations. Current studies categorize sounds into either stationary or moving, but this division does not necessarily apply to natural or realistic sounds that involve stationary and moving components. In addition, it appears from previous studies that salience of the sounds is important. To our knowledge, the study of natural sounds within proper contexts has not been comprehensively addressed in the literature and may further shed light on the underlying mechanism of increased fall risk in individuals with hearing loss in real-life environments. The use of headphones for providing 3-dimensional information should be further tested owing to the clinical implications and simpler setup of headphones vs speakers.

Balance Paradigm

Future studies on sound and posture in adults should include an adequate level of balance challenge. If the task is challenging enough, perhaps we will observe integration of auditory cues regardless of the level of attention. In addition, most of the studies in this review investigated the importance of sounds for postural control when visual cues were completely removed. Studying the simultaneous integration of diverse visual stimuli and generated or natural sounds may promote understanding of how sighted individuals may be using sounds for balance in real-life situations. Virtual reality technology presents an opportunity to develop immersive balance paradigms that are ecologically valid. Testing sound integration during dynamic balance and gait tasks will also enhance the ecological validity of the findings because most falls happen during movement.

Limitations

This narrative review has several limitations. Despite the large number of studies published on this topic since 1990, combining the results into a cohesive conclusion proved challenging. The auditory paradigms varied among studies, and inconsistent results were occasionally found among studies that applied a similar testing paradigm. This review synthesized studies on standing balance. We did not include auditory paradigms that appeared only once in the literature or had an emotional component such as music.

Conclusions

Stationary broadband sound (white noise or environmental sounds) may serve as an auditory anchor for balance primarily when projected through speakers and when the balance task is challenging. A stationary pure tone was not associated with changes in sway. Moving sounds were typically associated with increased sway when projected through headphones. In individuals with vestibular or hearing loss, but not in those with a unilateral cochlear implant, moving sounds appeared to be more destabilizing than in healthy controls. Auditory cues and the presence of hearing loss should be considered in balance and fall risk assessments.

ARTICLE INFORMATION

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Drafting of the manuscript: Lubetzky, Gospodarek, Arie, Kelly, Cosetti.
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