Review Article

A Review on the Measures of Auditory Cognition in Individuals with Vestibular Disorders

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Short running title: A Review on the Measures of Auditory…

Highlights:
- Reviews links between vestibular dysfunction and auditory-cognitive effects
- Highlights inconsistent evidence linking vestibular issues to cognitive deficits
- More studies on various cognitive aspects are needed for broader generalization

ABSTRACT
Background and Aim: The vestibular system, which involves the peripheral vestibular apparatus and central vestibular pathways, is crucial for balance and posture. In addition to its primary functions, the vestibular system is closely linked with cognitive processes, as evidenced by its connections with the neocortex and limbic system. Vestibular dysfunction has been associated with cognitive impairments, particularly in areas of auditory cognition, where allocating cognitive resources for balance maintenance detracts from higher cognitive functions. This review examines the existing literature on the auditory-cognitive consequences of vestibular dysfunction.
Recent Findings: This systematic review gives comprehensive information about the existing research on the impact of vestibular pathology on auditory cognitive abilities. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, 226 articles were initially identified, with six studies meeting the inclusion criteria after thorough screening. The review highlights the varied effects of vestibular dysfunction on auditory cognition, revealing significant impairments in auditory working memory and attention, particularly in conditions like bilateral vestibulopathy and vestibular migraine. However, inconsistencies in the literature regarding specific vestibular pathologies and their impact on auditory cognition underscore the need for further targeted research.

Conclusion: The findings suggest a complex interplay between vestibular function and auditory cognition, with implications for the diagnosis and management of cognitive deficits in individuals with vestibular disorders.
Keywords: Attention; memory; vertigo; giddiness; vestibular disorders

Introduction

The orientation of the human body in space is determined through various sensory inputs, viz the proprioceptive inputs from the skeletal muscles, the auditory neurons of the hippocampus, multimodal neurons of the posterior parietal cortex, visual system, and the vestibular system [1-4]. According to numerous early morphological and electrophysiological investigations, numerous neuronal connections from the vestibular nucleus to regions of the neocortex and limbic system are observed that are linked to learning and memory [5-8].

It has been observed that balance issues primarily affect the brainstem and cerebellar regions, followed by areas in the frontal cortex, including the superior frontal gyrus, primary motor cortex, inferior orbitofrontal cortex, and supplementary motor areas [9]. Balance-related issues also affect regions that include the hippocampus, basal ganglia, thalamus, occipital, and parietal areas [9]. Whereas the insular regions, corpus callosum, and ventricles/paraventricular regions are the least affected areas. Since the frontal cortex is crucial for attention, balance disorders may also impair attention [10]. Thus, there is likely to be a connection between the vestibular system and the structures involved in cognition. This was further justified by reports available on vestibular dysfunction and balance disorders in cognitively challenged individuals and vice versa [11-14]. Research also suggests that vestibular dysfunction can negatively impact cognitive performance [15-21]. This may be due to the increased cognitive load required for maintaining balance and posture —typically automatic tasks that become effortful in individuals with vestibular disorders [15, 22]. As cognitive resources become fatigued, individuals with vestibular dysfunction may experience disorientation and confusion. Cognitive tasks are negatively affected in individuals with vestibular dysfunction [23]. Individuals with Benign Paroxysmal Positional Vertigo (BPPV), which is one of the most common vestibular disorders, are reported to be more prone to dementia [18].

Common vestibular pathologies include BPPV, vestibular migraine, Meniere's disease, superior semicircular canal dehiscence, vestibular schwannoma, and labyrinthitis. While some vestibular disorders are associated with hearing loss, others manifest independently of auditory impairment. For instance, Meniere's disease, vestibular schwannoma, and labyrinthitis are vestibular disorders often associated with hearing loss [24-26]. Auditory perceptual skills and cognition are poor in individuals with hearing impairment [27, 28]. Thus, auditory impairment can complicate the evaluation of vestibular disorders' specific effects on auditory perception and cognition. In contrast, BPPV and vestibular migraine are not typically associated with hearing loss but have been linked to auditory-related abnormalities [29-31].

The relationship between cognitive and auditory perceptual abilities is well-established, with evidence indicating that auditory processing —particularly dichotic and temporal processing —is closely tied to executive function, memory, and overall cognitive health [32-35]. This interdependence highlights the need to explore how vestibular pathology may impact auditory cognitive abilities, underscoring the intricate connections between vestibular function, cognition, and auditory processing. Despite increasing research on vestibular dysfunction and its cognitive implications, the specific effects on auditory cognition remain underexplored. Given the shared neural pathways and overlapping functions between vestibular and auditory systems, understanding how vestibular pathologies influence auditory perceptual and cognitive abilities is essential. Such insights could enhance clinical assessment, improve rehabilitation strategies, and contribute to a more comprehensive understanding of the broader cognitive and sensory impacts of vestibular disorders. Therefore, this review aims to bridge this gap by examining the existing literature on the auditory-cognitive consequences of vestibular dysfunction and highlighting areas for future research.

Methods

The study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [36].

Eligibility criteria

The literature search was done for articles published after 2002. Experimental studies were chosen for systematic review, and systematic reviews were excluded. The population of interest was individuals with vestibular disorders. Articles related to cognitive issues were included. Articles that included populations with vestibular disorders, along with other audiological complaints, were excluded since auditory issues would have an impact on the auditory skills of the participants, thereby affecting the results of the cognitive tasks. The experimental group should have at least 10 participants, with or without the control group. Articles published in languages other than English were excluded from the review process.

Search strategy

The electronic databases, PubMed, Google Scholar, and the institutional repository of All India Institute of Speech and Hearing were searched. The keywords used were as follows: “vertigo”, “dizziness”, “vestibular disorders”, “vestibular loss”, “vestibular dysfunction”, “migraine”, “spinning sensation”, “cognition”, “auditory cognition”, “auditory processing”, “auditory working memory”, and “Auditory attention”. The keywords were combined with the Boolean search operators to search.

Study selection

After the database search, a three-step process was used to review all studies according to the eligibility criteria: title screening, reading the abstract, and reading the full text. The full text was retrieved for all potentially relevant records meeting the inclusion criteria or for insufficient information in the title and abstract to make a firm decision.

Quality assessment

The quality assessment of the included studies was done by the authors using the National Institute of Health (NIH) Quality Assessment Tool for Case-Control Studies, Observational Cohort, and Cross-Sectional Studies. Each study was evaluated to determine the risk of bias and then categorised as good, fair, or poor based on the assessment score. Only studies that received ratings of good or fair were included in the review process. Grey literature was excluded to maintain the reliability of the sources, as many grey literature documents lack formal peer review.

Results

The search process is represented in Figure 1. A total of 226 articles were obtained from the database search. The articles were exported to the Rayyan software to identify and remove the duplicated articles, and 28 duplicates were removed. Title and abstract screening were carried out, and the full texts were screened to select the articles based on eligibility. The number of articles removed at different levels due to not fitting into the criteria is given in Figure 1. After the screening process, six articles were included in the systematic review. Details of the literature reviewed related to auditory cognition in individuals with vestibular dysfunction are given in Table 1.

Discussion

Based on the above-reviewed articles, results have been discussed under two headings based on the outcome of the electrophysiological studies and behavioural test findings. The above review is a testimony of limited research work using electrophysiological tests, whereas behavioural tests have been used relatively more to observe the impact of vestibular disorders on cognition.

Electrophysiological evidence

The most commonly used electrophysiological test that assesses cognitive ability in individuals with vestibular disorders is P300, which requires active attention and is a measure of cognition. The above literature indicates that electrophysiological studies like P300 showed an increase in latencies among those who had vestibular pathology compared to those who did not have such disorders. Also, the amplitude and latency parameters of P300 were observed to be more affected with the increase in the severity of the vestibular pathology [37]. This indicates that the greater the severity of the dizziness, the more the likelihood of cognitive impairment [37]. Similarly, Kumar et al. also observed that P300 was absent in more individuals with vestibular dysfunction, with a statistically significant correlation between vestibular dysfunction and the presence or absence of P300, indicating impaired attention [38]. However, they also observed no significant difference in latency and amplitude of P300 between individuals with vestibular dysfunction, among those with present P300 peaks and those with normal vestibular function [38]. Thus, electrophysiological evidence suggests that vestibular abnormality is likely to affect auditory attention, though it may not be similarly affected in all individuals affected by vestibular problems. This may be attributed to anatomical alterations in brain structures associated with auditory P300 generation in individuals with vestibular dysfunction.

Behavioural evidence

The above review indicates that the research on behavioural tests for cognition (attention and memory) that rely on auditory modality is sparse in individuals with vestibular dysfunction. Studies mentioned above showed no significant difference in attention and memory assessed through auditory modality compared to tests that relied on visuospatial modality [16, 39-42] among the individuals with vestibular loss and normal controls. This suggests that nonvisual and nonspatial cognitive domains may not be significantly associated with vestibular function [39].

However, Danneels et al. have observed poor auditory and visual working memory in individuals with bilateral vestibular pathology [17]. Disruptions in cognitive processing and motor actions were also evident in these individuals for both visual and auditory exercises. Ayar et al. reported that the auditory forward digit span in individuals with vestibular dysfunction is similar to that of individuals with normal vestibular function [43]. However, the backward digit span was significantly low in individuals with vestibular dysfunction. Authors have also assessed Beck Depression and Anxiety inventories and found some association between Beck depression score and anxiety inventories for these individuals and concluded that it could negatively influence the performance of individuals on these tests. When emotional factors were statistically accounted for using multivariate analysis, the cognitive test scores (measuring visuospatial abilities, psychomotor speed, and short-term memory) did not significantly differ from healthy controls. Thus, the authors concluded that emotional factors like anxiety and depression are probably influencing or exacerbating the cognitive deficits observed in vestibular patients rather than the vestibular impairment being the primary cause [43].

Contrary to the above research, auditory digit span showed no difference in individuals with vestibular dysfunction and normal vestibular function in both forward and backward conditions. However, the Corsi Block Tapping test (a visuospatial task that assesses short-term and working memory) showed that individuals with vestibular dysfunction had significantly poorer scores than individuals with normal vestibular function. This difference in the visuospatial and the auditory task suggests that the vestibular-cognitive interaction is specific to visuospatial ability and may not affect cognitive tasks that mainly depend on nonvisual sensory cues [39].

A study by Tawfik et al. on individuals with vestibular migraine and migraine observed impaired memory function compared with individuals in the control group [29]. No significant differences were noted between individuals with vestibular migraine and those with migraine only. This suggests that underlying vestibular dysfunction might be a fundamental aspect of migraine as a whole rather than being specific only to vestibular migraine. Therefore, there is likely a significant overlap between the neural pathways involved in migraines and those involved in vestibular functions. This supports the idea that vestibular migraine is a variant of migraine with added vestibular symptoms [29].

It is expected that the vestibular abnormalities are likely to affect the patients' cognitive abilities or affect the results of the tests that assess the cognitive-related issues. Several pieces of literature support the link between the vestibular structure and other cortical structures responsible for cognitive tasks. Surgent et al. reviewed the brain structures involved in postural balance in humans [9]. They came to the conclusion that the most common affected areas were the brainstem and the cerebellar regions, followed by the superior frontal gyrus, primary motor cortex, inferior orbitofrontal cortex, and supplementary motor areas of the frontal regions, further followed by the hippocampal region and the subcortical regions such as the basal ganglia and the thalamus, occipital region and the parietal region in individuals with balance issues [9]. The right ventrolateral frontal cortex is engaged in auditory attention, while the right frontal eye field and the surrounding cortex are involved in both auditory and visual-spatial attention [10]. The amygdala, the hippocampus, the cerebellum, and the prefrontal cortex are the brain structures associated with memory [44]. Since these structures are affected in individuals with balance issues, vestibular dysfunction would have resulted in altered cognitive abilities like attention and memory in the vestibular dysfunction population. In most of the behavioral studies.

It is also noteworthy to mention that person with vestibular disorder might have associated problem like anxiety, diversion of attention etc. to pathology itself [43]. And this could also result in alters cognitive tests results rather than direct impact of vestibular pathology itself.

Conclusion

The findings of the reviewed studies were inconsistent, with some indicating significant auditory cognitive impairments in individuals with vestibular disorders, while others reported minimal or no effects. These discrepancies may stem from variations in sample populations, differences in cognitive assessment methods, duration of vestibular abnormality and the diverse types of vestibular disorders examined. To better understand the relationship between vestibular dysfunction and auditory cognitive processing, future research should focus on larger sample sizes, assess specific vestibular disorders, adopt standardized cognitive evaluation protocols, and incorporate longitudinal study designs to strengthen the research outcome.

Ethical Considerations

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The authors have not received any funding for the present study.

Authors' contributions

VV: Study design, acquisition of data, and drafting the manuscript; AB: Study design and supervision, interpretation of the results, and critical revision of the manuscript.

Conflict of interest

The authors have no conflict of interest to disclose.

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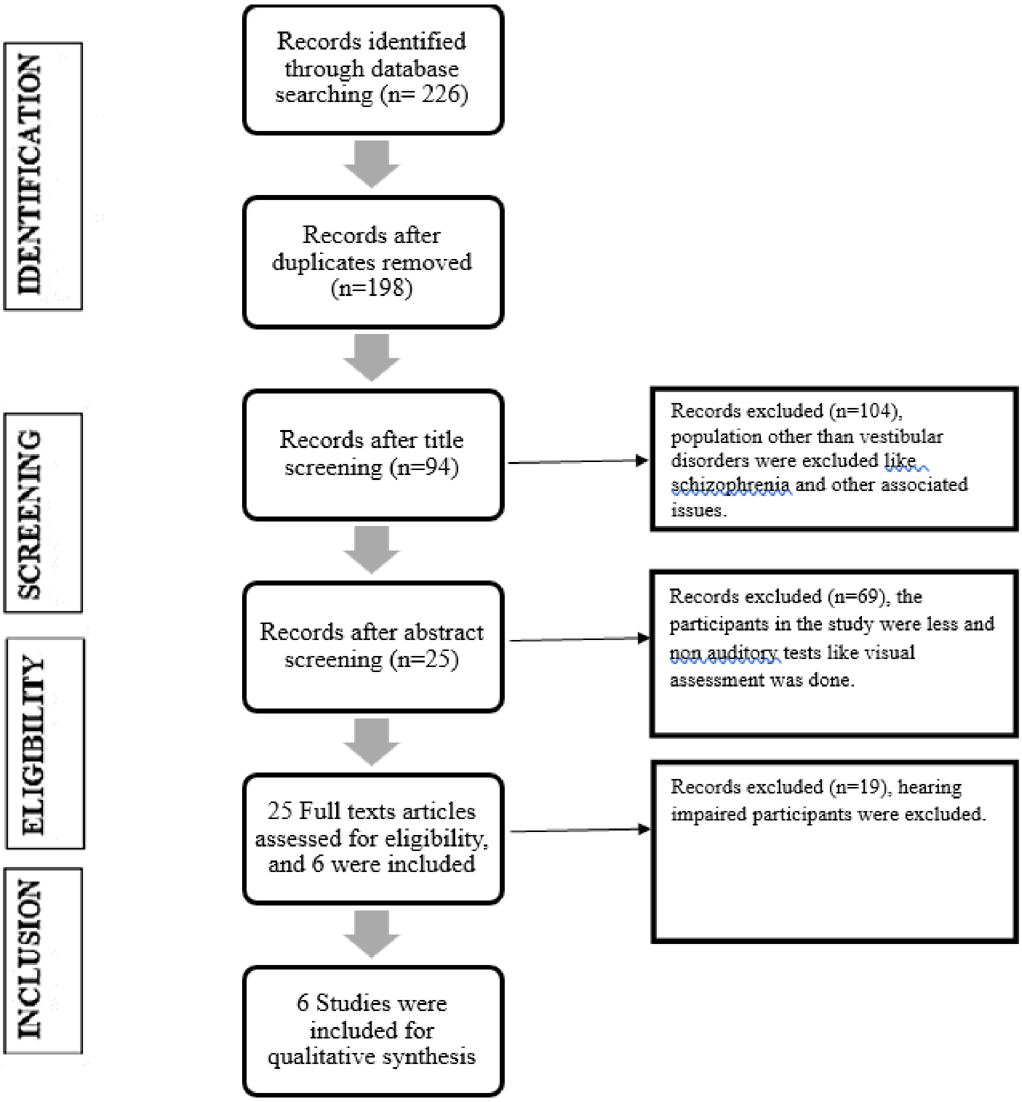

Figure 1. PRISMA flowchart for the selection process of articles in the review

Table 1. Vestibular dysfunction and cognition (auditory mode)

Sl. No	Title	Author	Objectives of the study	Population	Vestibular complaint/diagnosis	Tests used	Results
1.	P300 event-related potential predicts cognitive dysfunction in patients with vestibular disorders	Ma et al. [37]	To determine the cognitive impairment in older adults with vertigo and imbalance	79 older adult (mean age=68.4 years) patients with vertigo and imbalance, divided into mild group (n=20), moderate group (n=39), and severe group (n=20) according to the dizziness handicap inventory.	Vertigo and imbalance. Diagnosis not specified	Auditory P300 Dizziness handicap inventory scores, mini-mental state examination, generalized anxiety disorder-7, and patient health questionnaire-9	The P300 latencies increased significantly with the increase in the severity of vestibular symptoms. Similarly, significant amplitude reduction was seen with the increase in severity. Older patients with more severe symptoms of vertigo and imbalance are at higher risk of developing abnormal cognitive function.
2.	The impact of vestibular function on cognitive-motor interference: a case-control study on dual-tasking in persons with bilateral vestibulopathy and normal hearing	Danneels et al. [17]	To elucidate the impact of bilateral vestibular pathology on cognitive and motor performance and on cognitive–motor interference.	Patients with bilateral vestibular pathology (n=22, mean age=53.66) and healthy controls (n=22. Mean age=53.21)	Vertigo and imbalance. Diagnosis not specified	The mental rotation task, the Corsi block test, the coding task, the visual and auditory Stroop test, and the visual and auditory backward digit recall test.	The bilateral vestibular pathology group had significantly poorer mental rotation skills and auditory and visual working memory in single-task conditions. In the dual-task condition, the bilateral vestibular pathology group performed significantly poorer on the mental rotation task and the visual response inhibition task.
3.	Visuospatial cognitive dysfunction in patients with vestibular loss	Ahmad et al. [39]	To characterise visuospatial and non-visuospatial cognitive domains affected by vestibular loss and determine whether patient-reported outcomes measures correlate with performance on neuropsychological tests.	Sixty-nine age-matched subjects: Bilateral vestibular loss, n=25, mean age, 55.6 years), Unilateral vestibular loss (n=14, mean age, 59.8 years), and normal controls (n=30, mean age, 54.6 years).	Vertigo and imbalance. Diagnosis not specified	Digit span test (a component of the Wechsler memory scale), auditory Stroop test.	No significant difference was seen in DST and Stroop tasks among the participant groups in either the forward or reverse-order conditions.
4.	Cortical auditory potentials and cognitive potentials in individuals with and	Kumar et al. [38]	To compare the latency and amplitude of cortical auditory evoked potential and P300 between individuals with vestibular dysfunction and	Group I: 20 adults (mean age=40.5 years, SD=13.1) diagnosed with vestibular dysfunction. Group II: 20	Vertigo and imbalance. Diagnosis not specified	Cortical auditory evoked potential (P300)	There was no significant difference in the latency and amplitude of cortical potential peaks (p1, n1, p2, and n2). P300 was absent in a greater

	without vestibular dysfunction		individuals with no vestibular dysfunction.	age-matched adults with no vestibular dysfunction			number of individuals with vestibular dysfunction. There was a statistically significant correlation between vestibular dysfunction and the presence or absence of P300.
5.	Deficits in central auditory processing among migraine patients	Tawfik et al. [29]	To verify and compare auditory processing performance in migraine patients with and without dizziness and healthy controls.	Sixty subjects were divided into three groups: control group (n=20, mean age=34.8 years), study group I (n=20, mean age=33.8 years) diagnosed with migraine and study group II (n=20, mean age=34.25 years) diagnosed with vestibular migraine.	migraine and vestibular migraine	Arabic memory test and Arabic speech intelligibility in noise test	Migraine patients (groups I and II) showed impaired memory function in all tests, including recognition memory, memory for content, and memory for sequence tests. The three groups showed statistically significant differences in SPIN test results between the two study groups and the control group. However, there was no significant difference between the migraine group and the vestibular migraine group.
6.	Cognitive functions in acute unilateral vestibular loss	Ayar et al. (43)	To evaluate different domains of cognition in patients with acute unilateral vestibular loss in addition to assessing anxiety and depression.	Group 1: patients with acute unilateral vestibular loss (n=20, mean age=54.3 years) group 2: healthy controls (n=13, mean age=49.3 years). Patients with central vestibular involvement were excluded.	Vertigo and imbalance. Diagnosis not specified	Forward and backward digit span test, oktem verbal memory process test	Oktem verbal memory process test, forward digit span test results of the patients were not significantly different from the results of the healthy controls. On the other hand, scores of backward digit span were significantly low.