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ARTICLES

Cognitive skills involved in vestibular assessment and rehabilitation: an integrative review

Habilidades cognitivas envolvidas na avaliação e reabilitação vestibular: revisão integrativa

Habilidades cognitivas involucradas en la evaluación y rehabilitación vestibular: revisión integrativa

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Abstract

Introduction: The literature reports an association between imbalance and cognitive impairment. However, it is not yet clear which cognitive skills are involved with the vestibular system. **Objective:** To evaluate which cognitive skills are involved in vestibular assessment and rehabilitation in young and older adults. **Research strategy:** This is an integrative review of the literature, conducted between July and October 2020. The articles were selected through search in the main health databases – MEDLINE via PubMed, LILACS via Regional Portal of VHL, Cochrane, Scopus, Web of Science, and CINAHL, accessed via Portal CAPES, using the following descriptors "*Cognition*" OR "*Cognitive Dysfunction*" AND "*Vestibular Function Tests*" AND "*Vertigo*" AND "*Vestibular Rehabilitation*", and their equivalent terms in Portuguese and Spanish. **Selection criteria:** Articles published until 2020, investigating cognition with vestibular assessment or traditional and/or technology rehabilitation in subjects aged 18 years or older were included. Articles not available in full text or that used other types of treatment were excluded. **Results**: 16 out of the 6,965 articles initially retrieved met the inclusion criteria and were included in

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Authors' contributions:
MBNR: study conceptualization and design, article collection, analysis, and interpretation, manuscript writing, and review.
PCM: article analysis and interpretation, intellectually important article review, and final approval of the version for publication.
MACB: research supervision, intellectually important review of articles included in the review, and final approval of the version for public

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this review; 12 of them are cross-sectional, and four longitudinal studies. **Conclusion:** There was a relationship between uni- and bilateral vestibular dysfunction and working memory, executive functions, spatial navigation, and attention. The studies that conducted vestibular rehabilitation found improved overall cognitive skills, visuospatial capacity, attention, executive functions, spatial working memory, increased vestibulo-ocular reflex, postural control gains, and diminished psychological suffering.

Keywords: Cognition; Cognitive Dysfunction; Vestibular Function Tests; Vertigo; Rehabilitation

Resumo

Introdução: a literatura relata a associação entre o desequilíbrio e o comprometimento cogntivo, porém não é clara sobre quais habilidades cognitivas estão envolvidas com o sistema vestibular. **Objetivo:** avaliar quais habilidades cognitivas então envolvidas na avaliação e reabilitação vestibular em indivíduos jovens adultos e idosos. **Estratégia de pesquisa:** trata-se de uma revisão integrativa de literatura realizada entre julho e outubro de 2020, os artigos foram selecionados por meio das principais bases de dados da saúde MEDLINE via PubMed, LILACS via Portal Regional da BVS; Cochrane, Scopus, Web of Science, e CINAHL acesso via Portal CAPES, utilizando os descritores "*Cognition*" OR "*Cognitive Dysfunction*" AND "*Vestibular Function Tests*" AND "*Vertigo*" AND "*Vestibular Rehabilitation*" e seus correlatos em português e espanhol. **Critérios de seleção:** Foram incluídos artigos publicados até 2020 que investigaram a cognição com avaliação e reabilitação vestibular (tradicional e/ou com tecnologias) em indivíduos acima de 18 anos. Foram excluídos artigos que não possuíam texto completo disponível ou que utilizaram outra forma de tratamento. **Resultados**: dos 6965 artigos resultantes da busca inicial, 16 foram incluídos na presente revisão por satisfazerem os critérios de inclusão. Destes, 12 são estudos transversais, e quatro, estudos longitudinais. **Conclusão:** observou-se relação entre disfunção vestibular uni e bilateral com a memória de trabalho, funções executivas, navegação espacial e atenção. Nos estudos que realizaram a reabilitação vestibular encontrou-se melhora das habilidades cognitivas em geral, capacidade visuoespacial, atenção, funções executivas, memória de trabalho espacial, aumento do ganho do reflexo vestíbulo-ocular, do controle postural e uma diminuição do sofrimento psicológico.

Palavras-chave: Cognição; Disfunção Cognitiva; Testes de Função Vestibular; Vertigem; Reabilitação

Resumen

Introducción: la literatura reporta la asociación entre desequilibrio y deterioro cognitivo, pero no está claro qué habilidades cognitivas están involucradas con el sistema vestibular. **Objetivo**: evaluar qué habilidades cognitivas están involucradas en la evaluación y rehabilitación vestibular en adultos jóvenes y ancianos. **Estrategia de búsqueda**: se trata de una revisión integradora de la literatura realizada entre julio y octubre de 2020, los artículos fueron seleccionados a través de las principales bases de datos en salud MEDLINE vía PubMed, LILACS vía Portal Regional BVS; Acceso a Cochrane, Scopus, Web of Science y CINAHL a través del Portal CAPES, utilizando los descriptores "Cognición" O "Disfunción cognitiva" Y "Pruebas de función vestibular" Y "Vértigo" Y "Rehabilitación vestibular" y sus correlatos en portugués y español. **Criterios de selección:** Se incluyeron artículos publicados hasta 2020 que investigaban la cognición con valoración vestibular y rehabilitación (tradicional y / o con tecnologías) en mayores de 18 años. Se excluyeron los artículos que no tenían el texto completo disponible o que usaban otra forma de tratamiento. **Resultados**: de los 6965 artículos resultantes de la búsqueda inicial, 16 se incluyeron en esta revisión por cumplir con los criterios de inclusión. De estos, 12 son estudios transversales y cuatro estudios longitudinales. **Conclusión**: hubo relación entre la disfunción vestibular uni y bilateral con la memoria de trabajo, funciones ejecutivas, navegación espacial y atención. En estudios que realizaron rehabilitación vestibular se encontró una mejora en las habilidades cognitivas en general, capacidad visuoespacial, atención, funciones ejecutivas, memoria de trabajo espacial, aumento de ganancia en el reflejo vestibular-ocular, control postural y una disminución del malestar psicológico.

Palabras clave: Cognición; Disfunción cognitiva; Pruebas de función vestibular; Vértigo; Rehabilitación

Introduction

Cognition is a set of mental capacities that enable people to understand and solve every day problems[1]. The cognitive skills are as follows: memory, executive function, language, praxis, perception, and visuospatial function[1] – some of which are related to the vestibular system[2].

The vestibular system is critical to orientation and locomotion and interacts with various cognitive functions – e.g., navigation processes, spatial perception, body representation, mental images, attention, memory, risk perception, and social cognition[2,3,4,5]. The visuospatial function is the most often studied cognitive domain in research on vestibular dysfunction in humans, due to the connection between the vestibular system and the hypothalamus[6,7,8,9] .

The vestibular system involves neural connections from vestibular nuclei to limbic and cortical areas related to both spatial memory and cognition[6,7,8,9]. In this case, other cognitive domains, such as the executive functions, visuospatial function, attention, and memory, may be associated with vestibular dysfunction[6,9]. In the last decades, various papers have demonstrated the association between vestibular dysfunction and cognitive impairment[6,7,8,9]. These associations were confirmed by neuroimaging examinations that revealed hippocampal atrophy and impaired spatial navigation tasks in individuals with bilateral vestibular changes[6,9].

Vestibular dysfunction may be a determining factor for atrophy in areas of the vestibular cortical network – including the hippocampus, which is responsible for memory and visuospatial capacity[6,7,8,9]. Cognitive impairments, in their turn, are important risk factors for changes in motor performance and body balance – which highlights the importance of treatments that minimize the consequences of this dysfunction[6].

Vestibular rehabilitation (VR) is an effective method used to improve postural balance and prevent falls. It is indicated for patients with solely vestibular changes or central changes, and older people with multisensory impairment[3,4,10]. VR aims for vestibular compensation based on central neuroplasticity mechanisms known as adaptation, habituation, and substitution[3,4]. The objective of VR exercises is to improve vestibulo-visual interaction in head movement and increase static and dynamic postural stability when conflicting sensory information stimulates the labyrinth, sight, and proprioception[4].

Among other benefits, VR improves static and dynamic postural control, on the one hand decreasing both imbalance and depressive and anxiety symptoms, and on the other hand, increasing self-reliance and quality of life[4,5,11,12]. VR influences the gains in vestibulo-ocular reflex (VOR) and postural change. Vestibular changes seem to be associated with cortical regions, such as the limbic system and hippocampus, through vestibular nuclei pathways – cognitive structures involved in both memory and spatial orientation[5,11,12].

Despite the beneficial results of VR in the treatment of balance disorders and the known association between cognitive impairment and balance changes, there is yet no consensus in the literature about which cognitive skills are involved in vestibular dysfunction, and which can be improved with VR[6,11,13].

Objectives

To verify which cognitive skills are related to vestibular dysfunction, and which can be improved with VR in young and older adults.

Research strategy

This is an integrative review of the literature – which seeks to review topics important to clinical practice –, developed according to scientific recommendations[14]. Its research question was as follows: "Which cognitive skills are related to vestibular dysfunction, and which can be improved with VR?".

After defining the research question, the researchers developed this review in two stages. Altogether, the topic was identified and searched in the literature, the studies included in the review were categorized and evaluated, results were interpreted, and the knowledge presented in the articles was synthesized, following the methodology proposed in the literature [14].

The articles indicated in this study were researched between July and October 2020 in the main health databases, namely: MEDLINE via PubMed, LILACS via the Regional Portal of the Virtual Health Library (VHL), Cochrane, Scopus, Web of Science, and CINAHL via CAPES portal. The following descriptors and Boolean operators were used: "*Cognition*" OR "*Cognitive Dysfunc-*

tion" AND *"Vestibular Function Tests"* AND *"Vertigo"* AND "*Vestibular Rehabilitation*", and their equivalent terms in Portuguese and Spanish. Original articles published until 2020 in either open access or subscription journals were selected.

Selection criteria

Original research articles investigating cognitive skills with vestibular assessment (VA) and VR in young (18 years or older) and older adults (above 60 years) were included in the review. Articles whose title and abstract met the selection criteria regarding the topic defined by the authors were selected. After this process, the articles were read in full text. Cross-sectional, cohort and case-control studies were included in the final selection.

Following the criteria, articles that did not answer the research question that addressed VA and/or VR with cognition in children were excluded from this review, as well as abstracts in annals of congress and review articles. Based on the levels of scientific evidence, case studies, expert opinion articles, and duplicates were also excluded. Hence, 16 articles – 12 cross-sectional and four longitudinal studies – were selected for detailed analysis. The three researchers analyzed the exclusion of repeated texts due to overlapping keywords and of texts that did not describe the study object in all research stages that involved database searching and journal selection for inclusion in the research[14].

Data analysis

The three authors critically analyzed the selected articles; when they diverged, they analyzed by consensus the questionable articles. The selected studies were distributed according to two central themes, namely: 1) studies that analyzed VA with cognition; and 2) studies that analyzed cognition before and after VR. All selected articles were qualitatively analyzed, distributed into tables with the following items: authors and year of publication; study design; sample; number of participants and their age (minimum, maximum, or mean) and sex; study objective; vestibular tests; cognitive questionnaires, inventories, scales, and tests used; VR techniques and methods; results; and conclusion.

Results

The initial search found 6,965 full-text articles published in national and international journals – 815 in PubMed and 6,150 in Capes (2,135 in Cochrane, 1,281 in Scopus, 1,347 in Web of Science, and 1,387 in CINAHL); no article was found in VHL. After reading the title and abstracts, 116 articles were selected to be read in full text. Only 16 of these met the inclusion criteria, 12 of which are cross-sectional and four, longitudinal studies. The final corpus comprised 16 articles – three national and 13 international publications (Figure 1).

The articles were grouped by central themes and distributed into tables to present the results. For the analysis, the articles were divided into VA studies and VR studies, as shown in Charts 1 and 2, below.

The analysis of the selected studies revealed that the overall sample comprised 2,390 individuals of both sexes. Their age ranged from 18 to 91 years, with a mean age of 74 years. Two studies included only female participants[17,25].

Five out of the 16 articles included in this literature review had a control group matched for age and sex. Three of them were cross-sectional and two were longitudinal studies[18,20,25,26,30].

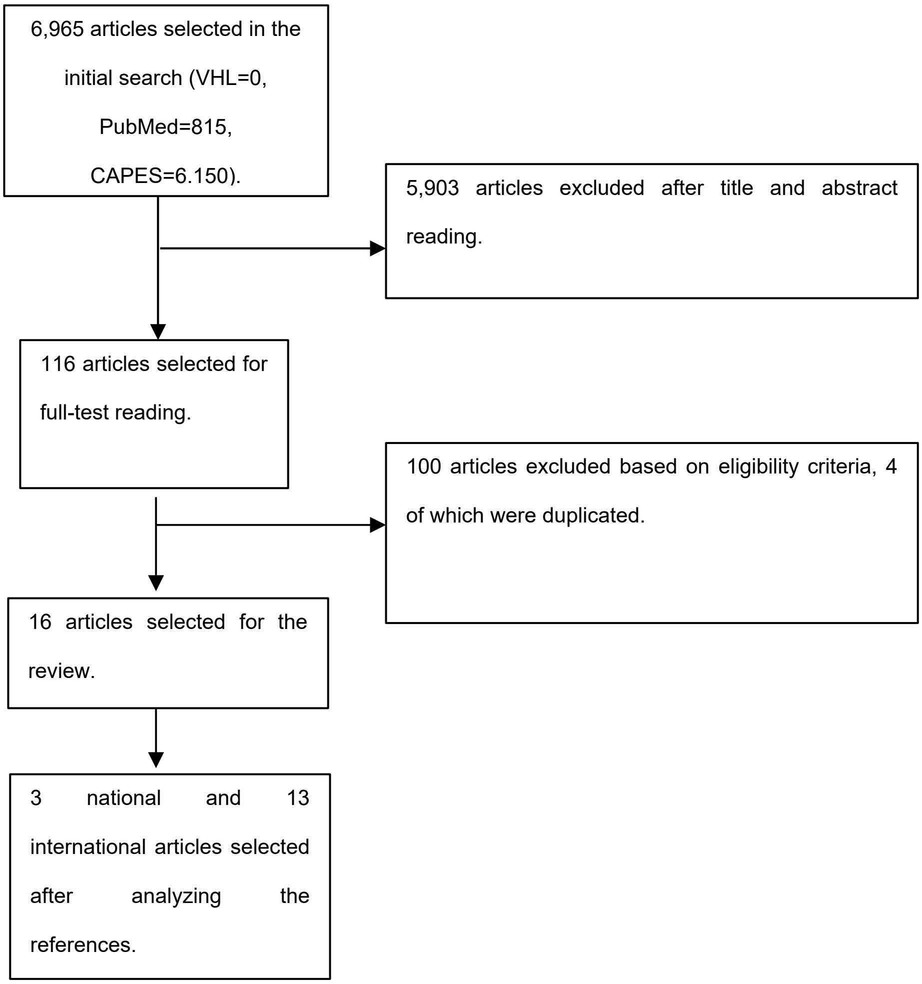

Figure 1. Flowchart with articles selected for the literature review..

Chart 1. Studies on vestibular assessment and cognition.

Authors (year of publication) and reference number	Study design	Sample	Objective	Vestibular tests, questionnaires, scales, and examinations	Cognitive tests	Results and conclusion
Caixeta, et al. (2012) Ref. 15	Contemporary cross-sectional cohort study.	76 participants of both sexes (> 60 years, with chronic peripheral vestibular dysfunction).	To assess the relationship between cognitive processing and body balance in older people with chronic peripheral vestibulopathies	BBS, DHI, DGI,TUGT, and TUGTm	MMSE, TR, and VF.	Associations between executive functions and imbalance. Worse cognitive results in higher imbalance values.
Borges, et al. (2013) Ref. 16	Cross-sectional study	56 female participants (60 to 95 years – 28 from the community and 28 from LTCF).	To compare the functional balance, risk of falls, tendency to depression, and cognition in older women	EEB DHI	MMSE, GDS	Institutionalized older women had worse results in cognitive and functional aspects, risk of falls, and depressive symptoms.
Bigelow, et al. (2016) Ref. 17	Cross-sectional analysis in a prospective cohort study.	183 participants of both sexes (26 to 91 tears).	To investigate the relationship between age-related vestibular loss and age-related visuospatial function decline	cVEMP	Card Rotations, Purdue Pegboard, Benton Visual Retention Test, and TMT	Vestibular loss was significantly associated with lower visuospatial, working memory, and attention scores
Wang, et al. (2016) Ref. 18	Cross-sectional study	120 participants of both sexes: 40 with vestibular migraine, 40 with simple migraine, and 40 controls. Their age ranged from 23 to 58 years.	To assess cognition and the quality of life in patients with vestibular migraine.	Diagnostic Criteria of International Migraine Association version 2	MMSE, CFT, TMT, VF Neuroimaging.	Greater cognitive impairment in MV (visuospatial, memory, and executive functions), greater incidence of brain lesions in neuroimaging, and lower quality of life.
Wei, et al. (2017) Ref. 19	Prospective cross-sectional study	50 participants of both sexes (> 55 years – 22 with MCI and 28 with AD)	To assess whether the vestibular loss is associated with precarious spatial cognitive skills.	cVEMP	MRMT, TMT-B, MMSE	Vestibular loss contributed specifically to a decline in spatial cognitive capacity in patients with MCI and AD.
Poop, et al. (2017) Ref. 20	Cross-sectional study	51 participants of both sexes (16 with unilateral vestibular changes (mean of 56 years), 18 bilateral (mean of 57 years), and 17 controls (mean of 52 years).	To explore the functional consequences of chronic vestibular insufficiency in different cognitive domains.	Electronystagmography v-HIT	TAP, Alertness and Visual Scanning, the Stroop Color-Word, and the Corsi Block Tapping Test.	The visuospatial skills, short-term memory, executive function, and attention were impaired in people with uni- and bilateral chronic vestibular dysfunction.
Wei, et al. (2017) Ref. 21	Cross-sectional study	60 participants, > 55 years: 21 with MCI and 39 with AD, of both sexes.	To assess whether the saccular impairment is associated with behavioral symptoms related to impaired spatial cognition, specifically losing objects, direction difficulties, and falls.	cVEMP	Visuospatial questionnaire, MMSE, and MRMT.	Saccular impairment contributed to impaired direction capacity, explained by the correlation between spatial cognition and saccular impairment.
Micarelli, et al. (2018) Ref. 22	Cross-sectional study	53 participants of both sexes (> 55 years) – 27 with MCI and 26 with AD.	To assess system integration rearrangements in unilateral vestibular hypofunction related to cognitive decline.	v-HIT, Posturography DHI, ABC, and DGI.	MMSE and (ADAS-cog).	Higher posturographic parameters in patients with unilateral vestibular hypofunction affected by AD than in those with MCI.

Authors (year of publication) and reference number	Study design	Sample	Objective	Vestibular tests, questionnaires, scales, and examinations	Cognitive tests	Results and conclusion
Lee, et al (2019). Ref. 23	Cross-sectional study	308 participants older than 50 years of both sexes with cognitive impairment.	To investigate whether increased dizziness in older people correlated with cognitive decline or postural instability.	DHI	MMSE, CDR, VF, BALDS, GDS, SGDS, NPI, DST Word Evocation, CD, and RCFT.	Attentional and visuospatial capacity was correlated with DHI. Postural instability was correlated with cognitive decline and increased dizziness.
Liu, et al. (2019) Ref. 24	Prospective cohort study	67 adults > 18 years, with a mean age of 53 years, of both sexes.	To quantify cognitive impairment in patients with dizziness.	DHI, v-HIT, cVEMP, and dynamic posturography.	NVI, (CFQ), (GAD7), (PHQ9), and SF20.	Patients with VM and DM had higher cognitive dysfunction levels than patients with BPPV.
Coelho, et al. (2020) Ref. 25	Cross-sectional study	22 older women (> 60 years) with chronic vestibular dysfunction (n = 11 moderate dizziness, n=11 severe dizziness) compared with 11 control older women.	To assess and correlate cognitive, balance, and gait aspects in older women with chronic peripheral vestibular dizziness and compare them with control older women.	DHI to divide the groups by degree of impact of dizziness, LoS, and WTs.	MEEM, MoCA, CD, VF, and TMT-B.	The relationship between cognitive change, imbalance, and gait change was stronger in women with severe dizziness than in those without vestibulopathies.
Breinbauer, et al. (2020) Ref. 26	Cross-sectional study	19 individuals with PPPD, 19 with vestibulopathies other than PPPD, and 18 controls. All of both sexes, aged 28 to 58 years.	To determine whether the performance in a virtual spatial navigation task is poorer in patients with PPPD than healthy subjects and patients with other vestibular dysfunctions.	Videonystagmography, v-HIT, and VEMP.	Virtual version of the MWM task and MoCA.	Patients with PPPD presented with more chaotic and disorganized seeking strategies than those in the non-PPPD group. This resulted in worse performance in spatial navigation tasks.

Legend: (ABC) Activities-specific Balance Confidence scale; (ADAS-cog) Alzheimer's disease scale; (BALDS) Barthel's Activities of Daily Living scale; (BBS) Berg Balance Scale; (MCI) mild cognitive impairment; (CDR) Clinical Dementia Rating; (CD) Clock Drawing; (CFQ) Cognitive Failures Questionnaire; (CFT) The Rey-Osterrieth Complex Figure Test; (AD) Alzheimer's disease; (DGI) Dynamic Gait Index; (DHI) Dizziness Handicap Inventory; (DST) Digit Span Tests; (GDS) Geriatric Depression Scale; (VF) Verbal Fluency Test; (GAD7) Generalized Anxiety Disorder-7; (GDS) Global Deterioration Scale; (LTCF) long-term care facility; (LoS) The Limits of Stability; (MMSE) Mini Mental State Examination; (MoCA) Montreal Cognitive Assessment; (MRMT) Money Road Map Test; (NPI) The Korean Neuropsychiatric Inventory; (NVI) The Neuropsychological Vertigo Inventory; (PPPD) Persistent Postural-Perceptual Dizziness; (PHQ9) Scale Patient Health 9-item Questionnaire; (RCFT) Rey Complex Figure Test; (SGDS) Short Version of the Geriatric Depression Scale; (TMT-A and B) Trail Making Test; (CT) Clock test; (TUGT) Timed Up-and-Go Test; (TUGTm) Timed Up-and-Go Test, modified; (TVA) Theory of Visual Attention; (VEMP) vestibular evoked myogenic potential; (v-HIT) Video Head Impulse Test; (WTs) Walking Tests; (SF20) 20-item Short Form Health Survey.

Chart 2. Studies on vestibular rehabilitation and cognition.

Authors (year of publication) and reference number	Study design	Sample	Objective	Vestibular tests, questionnaires, scales, and examinations	Cognitive tests	VR time	Results and conclusion
Sugaya, et al. (2018) Ref. 27	Longitudinal study.	60 participants (> 20 years, mean of 55 years), both sexes, assessed while institutionalized, 1 and 4 months after the intervention.	To investigate changes in visuospatial functions, attention, and executive function in patients with untreatable post-VR dizziness .	DHI, The center of gravity fluctuation measures, and (TUG test).	(TMT) and (HADS).	4 months, 30-minute weekly sessions.	Significant improvement in visuospatial capacity, attention, executive function, and dizziness and psychological suffering indices .
Sahni, et al. (2019) Ref. 28	Experimental Longitudinal study.	60 participants (60 to 75 years), both sexes, divided into 2 groups: 1- conventional exercise; and 2- Cawthorne and Cooksey method	To compare conventional VR with the Cawthorne and Cooksey method.	Conventional VR and Cawthorne and Cooksey method.	MMSE, Ruler Drop Test.	3 months, two 30-to-40-minute sessions a week.	VR helped improve cognition and eye-hand coordination in older people.
Micarelli, et al. (2019) Ref. 29	Longitudinal study.	47 participants (> 55 years), both sexes, 12 with vestibular change (mean of 74.3 years) and 12 with vestibular change and MCI (mean of 72.5 years) submitted to VR. 11 with vestibular change (mean of 76,9 years) and 12 with vestibular change and MCI (mean of 76.3 years) submitted to VR+HMD.	To analyze the results of applying HMD in older people with MCI and with unilateral vestibular hypofunction.	v-HIT, Posturography, DHI, ABC, and DGI.	MMSE	1 month, 30-to-45-minute weekly sessions. Virtual reality was used for 20 minutes per session.	Applying a virtual reality protocol at home improved VOR, postural control, and the quality of life in older people with MCI.
Guidetti, et al. (2020) Ref. 30	Longitudinal study	263 individuals with uni- and bilateral chronic vestibular hypofunction submitted to cognitive assessment before and after vestibular training, compared with 430 healthy individuals and 404 individuals with chronic vestibular hypofunction not submitted to training. Both sexes, aged 17 to 75 years.	To verify whether vestibular training can improve spatial working memory in individuals with chronic vestibular dysfunction.	Chronic vestibular loss for 3 or more months.	Corsi Span Test	5 consecutive days (8 one-hour sessions).	Vestibular training improved spatial working memory in individuals with greater vestibular dysfunctions.

Legend: (ABC) Activities-specific Balance Confidence scale; (MCI) mild cognitive impairment; (DGI) Dynamic Gait Index; (DHI) Dizziness Handicap Inventory; (HADS) The Hospital Anxiety and Depression Scale; (HMD) Virtual Reality Monitor; (MMSE) Mini-Mental State Examination; (TMT) The Trail Making Test; (TUG) The timed up-and-go test; (VR) Vestibular rehabilitation; (v-HIT) Video Head Impulse Test.

Discussion

This article reviewed studies approaching VA and VR associated with cognitive skills. The cross-sectional studies found that uni- and bilateral vestibular dysfunction was correlated with short-term memory, attention, executive and visuospatial functions, and spatial cognition[15,17,18,19,20,21,23]. Two of the studies that made a topodiagnosis of the lesion and whose sample had peripheral vestibular dysfunction found associations with executive functions and the overall score in the cognitive screening test that assesses orientation, attention, memory, language, calculation, praxis, and visuospatial and executive functions[15,25]. The study whose sample had central vestibular dysfunction found associations with memory and executive functions[18]. The study whose sample had peripheral and central vestibular dysfunction found associations with poorer performance in the vertigo cognitive screening test that assesses attention, memory, perception, praxis, and visuospatial function[24].

Five cross-sectional studies found associations between cognitive impairment and poorer performance in balance tests and/or greater impact of dizziness on the quality of life. Cognitive results were worse among individuals with vestibular diseases and/or greater impact of dizziness on the quality of life[16,22,24,25,26]. These findings corroborate the literature, which points to worse cognitive results in individuals with greater vestibular dysfunctions[6,9].

One of the selected longitudinal studies, whose sample comprised individuals with peripheral vestibular dysfunction, found improved cognitive domains, visuospatial capacity, executive functions, and attention, as well as diminished psychological suffering after VR[27]. Two studies whose samples did not have a topodiagnosis of the vestibular lesion found improved visuospatial skills, working memory, and overall results in the cognitive screening test[28,30]. One study found improved quality of life and postural balance in older adults with peripheral dysfunction and mild cognitive impairment (MCI) after VR with virtual reality[29]. Thus, attention, executive functions, working memory, and visuospatial functions were the domains with the best post-VR results. This shows the benefits of this treatment to the person's comprehensive health, regardless of where the vestibular lesion is located[4,5,11,12]. Cognitive skills improved with VR may be explained by the interaction between the vestibular system and the hypothalamus[31].

The interaction between the vestibular system and cognition is due to the communication of the vestibular pathways with the cortical areas, especially the hypothalamus, which are responsible for aiding in balance and maintaining attention, sensorimotor perception, visuospatial function, memory, body awareness, and social cognition[2,3,4,5,32,33,34]. The upper vestibular cortex is a network that interacts with other sensory systems, such as cognition, sensorimotor, motor, and visual cortex[35]. One study found brain changes (left hippocampus, right inferior frontal gyrus, bilateral temporal lobes, bilateral insular cortices, bilateral central opercular cortex, left parietal opercular cortex, bilateral occipital lobes, and cerebellum) in participants with persistent perceptual-postural dizziness. In comparison with controls, they had smaller connectivity between the areas involved in multisensory vestibular processing and spatial cognition and greater connectivity in visual linking and emotional processing[31].

Evidence of the relationships between vestibular function and cognitive performance was found in tasks that assess different neuropsychological domains. However, they were not conclusive, and few studies address this issue in humans[20,22,23,24,32]. One study found that saccular impairment, assessed with cervical vestibular evoked myogenic potential (cVEMP), was associated with a smaller hypothalamus in 1,100 participants – which confirms that hippocampal atrophy may impair spatial cognition[35]. Future studies may find other associations between the described cognitive functions and the vestibular function. Hence, it can be inferred that objective vestibular tests, such as VEMP and Video Head Impulse Test (v-HIT), are useful preclinical markers of MCI or dementia because the vestibular system connects with the temporal and parietal cortical areas and especially with the hippocampus. These areas are also affected by dementia, thus requiring further studies to better explain this interaction[6,31,32,35,36].

The longitudinal articles either did not assess memory, language, orientation, and praxis or assessed them only with a cognitive screening test, which was not reapplied after VR[27,28,29,30]. Four selected studies used the Geriatric Depression Scale (GDS), Short Version of the Geriatric Depression Scale (SGDS), Generalized Anxiety Disorder-7

(GAD7), and the Hospital Anxiety and Depression Scale (HADS)[16,23,24,27]. Assessing depression is important, as a depressive state may be often similar to MCI or a preclinical process of dementia – it is observed in up to 90% of patients diagnosed with dementia[37].

Regarding VR, the time of treatment in the selected studies ranged from 5 days to 4 months, each session lasting from 30 minutes to 1 hour[27,28,29,30]. The protocols they used were the Cawthorne and Cooksey method, static, dynamic, and oculomotor exercises, and virtual reality[27,28,29,30]. Improvements in cognitive skills are believed to result from the interaction between the vestibular system and cognition. In this regard, VR uses static, dynamic, and oculomotor exercises that activate the sensorimotor and visual systems and the pathways and structures of the vestibular system through VOR and vestibulospinal reflex (VSR). Thus, they stimulate the vestibular cortex, which interacts with the other cortical structures, forming the previously cited network of cortical information[2,3,4,5,10,31,33,34,35].

VR for older people with vestibular changes is important to help in drug treatments, as it has proved to be effective in the tested cognitive skills and balance improvement[3,4,5,10,11,38]. Therefore, VR helps people improve vestibular function, quality of life, and consequently the neuropsychological skills, aiming for their comprehensive healthcare[38].

Of the selected studies, 14 are from the field of Medicine[17,18,19,20,21,22,23,24,25,26,27,28,29,30], one from Speech-Language-Hearing (SLH) Sciences[16], and one from Physical Therapy[15]. The scarcity of publications in the field of SLH Sciences suggests that VA and VR have not been much studied in undergraduate SLH courses. This result is probably because VR is not addressed exclusively by SLH therapists; rather, it is a multidisciplinary practice[39] .

The limitations of this study include the few pieces of research investigating the relationship between the vestibular system and cognitive skills. Various studies only used cognitive screening tests, while studies that investigated post-VR cognitive skill improvements used neuropsychological tests limited to certain cognitive skills. Another important aspect is that international studies consider someone as an older adult when they are 55 years or older[19,21,22,29] – which may lead to differences in inclusion criteria in comparison with Brazilian studies. This literature review showed that SLH professionals who work with VA and VR need to further their studies on the vestibular system in relation to cognitive skills to provide comprehensive treatment to their patients.

Conclusion

The selected studies reported associations between uni- and bilateral peripheral vestibular dysfunction and working memory, executive functions, spatial navigation, and attention. Central vestibular dysfunction was correlated with memory and executive functions. People with vestibular migraine, Ménière's disease, and persistent dizziness had worse cognitive results.

After VR, people with peripheral vestibular dysfunction or without a topodiagnosis of the lesion improved their visuospatial function, attention, spatial working memory, and executive functions. Moreover, the VOR gain increased, the postural control improved, and the psychological suffering diminished in people with vestibular dysfunction.

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