EVIDENCE OF THE RELATION BETWEEN VESTIBULAR AND COGNITIVE SYSTEMS: LITERATURE REVIEW

EVIDÊNCIA DA RELAÇÃO ENTRE SISTEMAS VESTIBULAR E COGNITIVO: REVISÃO DA LITERATURA

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ABSTRACT: Introduction: Vestibular disorders occur in more than 35% of adults over 40 years. The incidence increases with age. An evident effect of vestibular dysfunction is dizziness. Patients with vestibular symptoms frequently complain about difficulties in cognitive skills (attention, memory, spatial location). **Objective:** To verify a possible relationship between the vestibular system and the cognitive system. Further, to examine whether physical exercising together with balance can impact positively on body balance and cognitive functions. **Method:** We made a literature search in July 2020 in the electronic databases. Relevant studies were identified by the criteria: papers in English, papers published between 2015 and 2020, keywords search by using the Boolean operator "AND": "vestibular system", "cognitive", "cognition", "balance training" and "exercise". Additional criteria for inclusion or exclusion: only original articles, experimental research with humans, articles that contribute to the understanding of concepts explored in the study, and articles with theoretical arguments that support or not the research. **Results:** Eight articles met the criteria and were considered eligible. **Conclusion:** The review suggests that body balance is causally involved in the performance of cognitive skills. Balance training by using physical exercise seems to be a promising intervention. It can be both a technique of cognitive intervention and improvement of corporal balance.
KEYWORDS: Dizziness, cognition, neuroplasticity, balance training

RESUMO: Introdução: Distúrbios vestibulares ocorrem em mais de 35% dos adultos com mais de 40 anos. A incidência aumenta com a idade. Um efeito evidente da disfunção vestibular é a tontura. Pacientes com sintomas vestibulares frequentemente se queixam de dificuldades nas habilidades cognitivas (atenção, memória, localização espacial). **Objetivo:** Verificar uma possível relação entre o sistema vestibular e o sistema cognitivo, além de verificar se o exercício físico aliado ao equilíbrio pode impactar positivamente no equilíbrio corporal e nas funções cognitivas. **Método:** Fizemos uma pesquisa bibliográfica em julho de 2020 em bases de dados eletrônicas. Os estudos relevantes foram identificados pelos seguintes critérios: artigos em inglês, artigos publicados entre 2015 e 2020, busca por palavras-chave utilizando o operador booleano "AND": "sistema vestibular", "cognitivo", "cognição", "treino de equilíbrio" e "exercício". Critérios adicionais de inclusão ou exclusão: somente artigos originais, pesquisas experimentais com seres humanos, artigos que contribuam para a compreensão dos conceitos explorados no estudo e artigos com argumentos teóricos que apoiem ou não a pesquisa. **Resultados:** Oito artigos atenderam aos critérios e foram considerados elegíveis. **Conclusão:** A revisão sugere que o equilíbrio corporal está causalmente envolvido no desempenho de habilidades cognitivas. O treinamento de equilíbrio por meio de exercícios físicos parece ser uma intervenção promissora. Pode ser tanto uma técnica de intervenção cognitiva quanto de melhora do equilíbrio corporal.
PALAVRAS-CHAVE: tontura, cognição, neuroplasticidade, treino de equilíbrio.

INTRODUCTION

Body balance results from the adaptive relationship between body and environment. It is an unconscious function trained from birth. To perform daily routine tasks, this complex function is required every moment.

Body balance is an important condition for humans, and it is not restricted to a single organ. Three fundamental systems take part in body balance: (i) vision, (ii) proprioception, and (iii) vestibular system. The latter integrates information (sensory signals) with central nervous system structures.

When the three sensory systems send information to the cerebral cortex in a conflicting manner, vertigo and dizziness occur. The most frequent related sensations by patients are spinning in the environment, imbalance, instability, spatial disorientation, fluctuation, heavy head feeling, drunkenness, and even the feeling of imminent death[1].

Epidemiological studies show that vestibular disorders occur in more than 35% of adults over 40 years. In the elderly between 60 and 69 years, the prevalence of dizziness is 50%. The occurrence is even higher in the ages between 70 and 79 years reaching around 69%[2]. Neuhauser (2016) states that compared to cases of cancer and cardiovascular disease, the epidemiology of dizziness is small, but with a great impact on the number of medical attention[3]. Ganança et al. (1998) stress that dizziness is the most common symptom in the world and the third most frequent medical complaint affecting more than 33% of people at some time in their lives[4]. Tehrani (2013) estimates that in the United States in 2011, approximately 3.9 million patients were treated in the emergency room suffering from dizziness[5].

The Brazilian estimative is blurry since there are few studies. For example, Bittar et al. (2013) estimate 42% of the prevalence of dizziness in the state of São Paulo[6]. Martins et al. (2017) discovered that dizziness symptom was the third prevalent in the state of Minas Gerais with high prevalence values reported only for the symptoms of fever and headache[7]. Ferreira et al. (2014) reported 74% of dizziness symptoms in elderlies. More studies should be realized since the occurrence of dizziness in Brazil is lacking[8].

The vestibular system controls body balance. An evident effect of vestibular dysfunction is dizziness. Patients with vestibular symptoms frequently complain about difficulties in cognitive skills (e.g., attention, memory, spatial location). These difficulties are rarely considered during the evaluation and treatment process[9]. One cannot ignore the fact that cognitive tasks and body balance are required constantly. Impairments in these functions cause negative impacts on the patient's quality of life.

To date, there is no comprehensive understanding of the relationship between the vestibular system and the cognitive system. However, some studies show evidence of the relationship between these two systems[10,11,12].

Vestibulopathy studies suggest poorer performance on cognitive tests compared with the control group[10]. For example, subjects who improved their body balance, particularly using balance training, presented better performance and cognitive evaluations on memory and space location tests[13]. Besides, brain imaging research showed structural changes in brain areas responsible for balance and cognition[10,14,15].

We reviewed the specialized literature to seek evidence of the relationship between the vestibular system and the cognitive system. The recognition of this correlation could guide the assessment and therapy of patients with balance disorders as well as patients with cognitive complaints.

This review aims to verify a possible relationship between the vestibular system and the cognitive system. Further, to examine whether physical exercising together with balance can impact positively on body balance and cognitive functions.

We hypothesize that there is a relationship between both systems. Moreover, vestibular stimulation through physical exercising/balance can benefit cognitive functions and body balance.

METHOD

Two questions guided the research: (1) Is there a relationship between the vestibular system and the cognitive system? (2) Can physical exercising together with balance demands impact positively on body balance and cognitive functions?

A literature search was conducted on July 2020 in the electronic databases: Oxford Journals (Oxford University Press), Springer (CrossRef), Taylor & Francis Online – Journals, SpringerLink, PMC (PubMed Central), Science Direct Journals (Elsevier) MEDLINE/PubMed (NLM) and Scopus (Elsevier).

Potentially relevant studies were identified by the following search strategy: (a) papers in English, (b) papers published between 2015 and 2020, (c) keywords search by using the Boolean operator "AND": "vestibular system", "cognitive", "cognition", "balance training" and "exercise".

Additional criteria for inclusion or exclusion of articles were: (a) only original articles, (b) experimental research with humans, (c) articles that contribute to the understanding of concepts explored in the research, and (d) articles with theoretical arguments that support or not the research hypotheses.

The questions proposed in this study followed the PICO strategy: P = Patient, problem or participant, I = Intervention, C = Comparators, and O = Outcomes. Thus, the population included patients with vestibulopathy and/or healthy subjects of any gender and age. It was not possible to carry out statistical analysis since the studies used different methods. Therefore, our review is qualitative.

The intervention comprised physical exercises with balance demand. Comparators were balance tests and/or cognitive tests and/or imaging tests, and the results. Hence, we try to verify the hypothesis that guides this research.

RESULTS

Initially, we read titles and abstracts of 245 articles retrieved from the database search. After the initial step, only 42 remained in the study (Figure 1). We read those articles in full. Eight articles met the defined criteria and were considered eligible for the study.

It is noteworthy that the method chosen to guide this work does not exclude the inclusion of relevant articles to the research that may not be found in the search. The main findings of the 8 articles are summarized in Table 1.

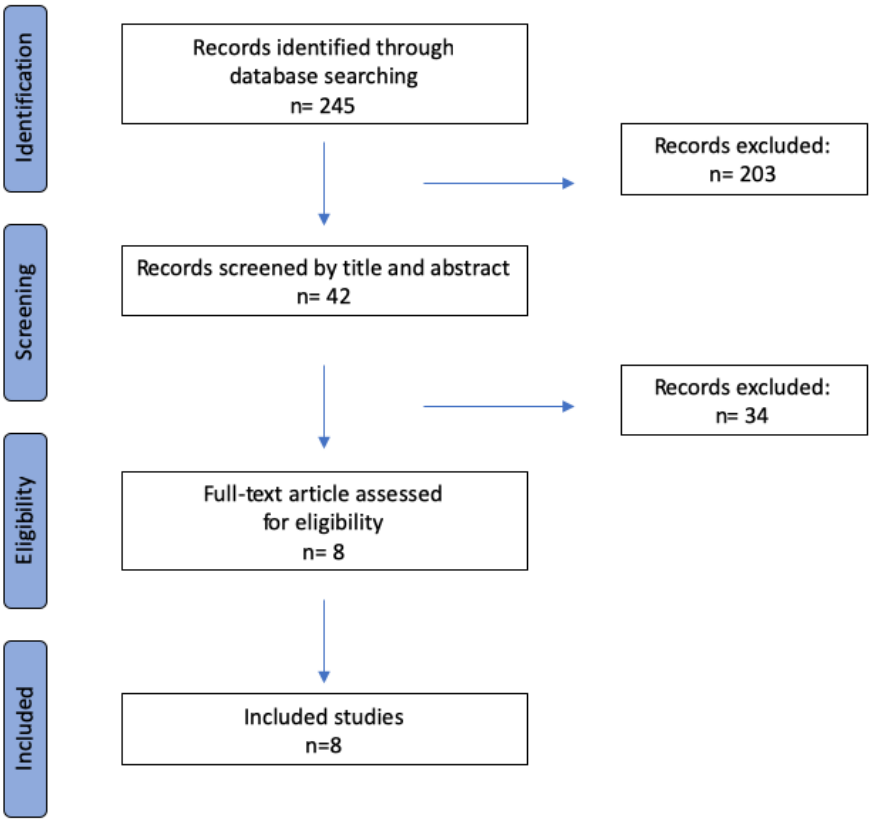

Figure 1 – Flow diagram

Table 1 – Literature review				
Author/ Year	**Participant**	**Intervention**	**Comparators**	**Outcomes**
Dordevic et al., 2017	50 healthy young. 18-30 years. Male and female.	Training group: 1-month intensive slackline training (3x a week, 10 min. strength and 50 min. Slackline). Control group.	Clinical balance tests (static stable and unstable surface – open and closed eyes; and dynamic). Spatial orientation test (active and passive walking in wheelchair condition – closed eyes).	Better performance in the training group compared with the control group in clinical balance tests (closed eyes condition). Better results in spatial orientation test compared with the control group (passive wheelchair condition).

Subramaniam S, Bhatt T, 2017	10 Yoga practitioners. 10 non-practitioners. Male and female.	Yoga (Hatha & Kundalini) 45 – 60 min. 2 – 3 a week.	Limits of stability tests Motor control test. Sensorial organization test (Posturography) Cognitive test: subtraction. Single and dual tasks.	Yoga practice can reduce cognitive-motor interference. It can improve the allocation and utilization of attentional resources for balance and cognitive functions. The result is better performance under dual-task conditions.
Popp et al., 2017	16 Unilateral vestibular loss (ULV). 18 Bilateral vestibular loss (BLV). 17 healthy control. 29-80 years. Male and female.	----------	Short-term memory, executive function, processing speed, and visuospatial abilities. Mini-Mental. Examination, Test for Attentional Performance, Stroop Color, and Word Interference Test, Corsi Block Tapping Test. Neurological and neuro-otological test (Electronystagmography, Head impulse test).	BLV: cognitive impairments in all domains. ULV: visuospatial impairments in 1 of 2 processing speed tasks. Control group: no alteration.
Rehfeld et al., 2017	52 healthy seniors. 63-80 years. Male and female.	Dancing. Aerobic training – Bicycle ergometer and Nordic Walking. 18 months – 2x 90 min. (6 months) and 1x 90 min. (12 months).	Magnetic resonance imaging. Balance Test - *Sensory Organization Test*.	Dancing training: increase in hippocampal volumes subdivisions. Improvements in balance tasks. Aerobic training: increase in hippocampal volumes.

Rogge et al., 2017	40 healthy participants. 19-65 years. Male and female.	Balance training Relaxation training. 12 weeks, 2x a week, 50 min.	Balance Test. Cognitive test (memory, spatial cognition, and executive functions). Cardiorespiratory fitness (spirometry).	Only the group of balance training showed improvements in balance, memory, and spatial cognition. No improvements were observed in executive functions and cardiorespiratory system.
Rogge et al., 2018	37 healthy participants. 19-65 years. Male and female.	Balance training. Relaxation training. 12 weeks, 2x a week, 50 min.	Magnetic resonance imaging.	Only the group of balance training showed improvements in balance and increase in cortical thickness of temporal, occipital, and frontal lobes.
Lüder et al., 2018	28 healthy adolescents. 12-13 years. Male and female	Balance training. Balance training + cognitive task. 8 weeks – 20-30 min.	Static and dynamic postural control (Posturography) in single- and dual-task.	Dynamic balance + cognitive task = cognitive performance impaired. Improvements after balance training and cognitive task + balance training.
Xiao et al., 2020	78 middle-aged and older adults. Male and female.	Tai Chi. 6 week, 60 min., 3x a week and 6 week, 90 min 5x a week.	Montreal Cognitive Assessment (visuospatial ability, attention, executive function, language, orientation, memory, and abstraction). Static balance in unilateral stance (left and right). Dynamic balance (TUG).	Better scores in static balance in unilateral stance (left). Better in TUG after training. Scores. Positive correlation between cognitive and balance functions after Tai Chi exercising. Tai Chi or balance training can improve balance and cognitive functions in middle age and older adults.

DISCUSSION

According to the articles analyzed here, the samples of subjects (adolescents, adults, and elderly) comprise both sexes. The studies were conducted with both healthy and people with vestibular failure (unilateral and bilateral).

The articles identified a relationship between the scores obtained in cognitive assessments with cortical structures and the efficiency of different training (dancing, balance training, fitness sport, relaxation, and Yoga).

Identifying the most efficient training that yields effective results in cognitive assessments is essential for designing rehabilitation therapies. Furthermore, inducing neuroplasticity is a technique that can improve cognitive functions.

The studies assessed here have small samples, although converged to a positive association between the vestibular and cognitive systems. The experiments involved distinct groups with different interventions and assessments. This condition hindered proper quantitative data analysis.

However, it was possible to carry out a behavioral analysis. The training sorted out by the researchers, except for relaxation training, proved to be beneficial to cognition and body balance.

The results corroborate the hypothesis that physical exercises that require balance such as dancing or slackline, can impact positively on cognitive functions.

Popp et al. (2017) showed that the group with bilateral vestibular loss leads to poorer results in cognitive tests compared to the group with unilateral vestibular disorders and control groups. The authors suggest that one intact labyrinth is sufficient to maintain the main cognitive function[17]. This is possible thanks to the neural reorganization (neuroplasticity) and compensation.

Although there is no further detail on the cause of these results, the researchers objectively found that cognitive skills are impaired in vestibular dysfunction. This is significant evidence of the causal relationship between the vestibular and the cognitive systems.

Brandt et al. (2005) present more evidence in favor of the interaction between both systems[10]. They were pioneers in realizing the first study about space navigation by showing that this depends on the preserved vestibular function.

Patients with bilateral vestibulopathy take longer and covered longer paths to find the platform in the Morris water task virtual variant, when compared to the control group. The authors add that poor performance in spatial memory and navigation tests coincide with hippocampal atrophy pattern.

The relationship between spatial memory and hippocampal volume was also verified by Maguire et al. (2000) in an experiment with taxi drivers[14]. The hippocampus is known for its relevant role in memory and learning.

According to the authors, this structure seems to store the spatial representation of the environment and it expands in response to environmental demands. Furthermore, hippocampal volume tissues reorganize after new experiences. The combination of the previous two studies highlights the causal relationship between the hippocampus and vestibular disorders.

In their studies, Popp and Brandt used patients with vestibular impairments to show the

interaction between vestibular and cognitive systems. Likewise, it is possible to identify this relation in healthy people. For example, the seven cases selected in this review. The measure of balance, cognitive skills, and imaging studies was realized before and after the intervention of balance training.

The development of techniques to induce neuroplasticity as well as the preservation and rehabilitation of cognitive functions, is a matter of great interest and relevance. Therefore, discovering which intervention is most effective for cognitive and balance enhancement has a great benefit; not only for the progress of therapeutic strategies but also for early stimulation and even guiding of leisure activities.

Some familiar exercising such as Yoga[16] and Tai Chi[19] seems to enhance balance and cognition. Trained and spontaneous balance by using Yoga and Tai Chi improves the allocation and utilization of attentional resources to cognition. As a result, there is a reduction in cognitive-motor interference.

Lüder et al. (2018) also point out cognitive-motor interference, e.g., dual-task studies. By the same token, training balance showed improvements in this relationship even in adolescents[12].

This type of study is illuminating because one can perform regularly dual-task behaviors such as walking around while talking on the phone or with a friend, climbing a ladder while trying to solve a mathematical equation, running to catch the bus while talking on the phone, among others.

Any simple tasks require cognitive control and balance control. Interference during the performance of dual-tasks is a significant factor in the occurrence of imbalance and falls, especially in the elderly[20].

Physical exercising that generates sensory, visual, proprioceptive, and vestibular integration is the most beneficial for the vestibular and the cognitive system. Thus, they are promising alternatives for cognitive intervention.

The results of cognitive tests may be dependent on the subject's motivation and commitments at the time of the assessment or on previous knowledge about the test. However, it is a simple and inexpensive test to assess cognitive skills.

Despite the higher cost, the results from MRI studies show structural changes in areas responsible, for example, for cognition. The research carried out by Rogge et al. (2017 and 2018), shows interesting data since the studies are complementary[15,18]. In the first, the authors performed balance assessment and cognitive tests. In the second, they realized magnetic resonance scanning.

The result of the two works converges towards a positive relationship between the vestibular and cognitive systems, not only with functional evidence using better scores, but also with a change in the thickness of cortical tissue in important areas for balance and cognition (temporal, occipital, and frontal lobes). Thus, the authors suggest that balance training can stimulate neuroplasticity in regions involved in these processes.

Structural changes were also observed by Rehfeld et al. (2017) in similar studies. After training with the demand for balance, in the case of dance, it was observed improvement in balance in the participants[11].

Furthermore, there was an increase in the volume of the hippocampus detected by magnetic resonance scanning, showing hippocampal plasticity after the exercise. Nonetheless, the research did not evaluate cognitive skills. Similar to Brandt et al. (2005), Rehfeld et al. (2017) confirm the relationship between the hippocampus and vestibular systems.

Specifying the role of the hippocampus in memory, learning, spatial location by assuming a causal relationship between the hippocampus and vestibular system, physical exercising with balance training, is a powerful strategy of prevention, preservation, treatment, and rehabilitation of body balance and cognitive functions.

The methodological plurality in the studies assessed here hindered the realization of statistical analyses. However, we observed that balance training seems to be beneficial not only for people with vestibular disorders but also for healthy people.

In sum, balance training contributes positively to wellness and cognition since it can soften the effects of natural aging or even in cases of neurodegenerative diseases as suggested by the studies reviewed here.

FINAL REMARKS

We reviewed different types of studies concerning the relationship between vestibular function and cognitive skills. Empirical evidence such as functional evaluations detected by volumetric changes in cortical structures and studies that measured cognition and balance after balance training, show improvement in cognitive performance as well as in body balance.

Our study identified in the literature review, the relationship between vestibular function and cognitive systems. Also, we confirmed the initial hypothesis, viz there is a positive relationship between both systems. Furthermore, physical exercising together with balance make positive changes in body balance and cognitive functions.

The availability of this data is important for the advance of cognitive therapies, vestibular rehabilitation, and treatment of patients with neurodegenerative diseases. The inclusion of tests of cognitive skills is an additional strategy to evaluate patients who suffer from dizziness and body imbalances.

In future, the clinical practice could integrate the cognitive tests to develop cognitive therapies and neurorehabilitation in treating vestibulopathy patients. The vestibular system plays a key role in preserving body balance.

We conclude that the selected articles confirm that body balance is involved in the performance of cognitive skills. Yet the integration of vestibular and cognitive systems is not a hot topic. However, the empirical evidence reviewed here serve as support to advance the study of such association.

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