Vestibular Function in Older Adults With Cognitive Impairment: A Systematic Review

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Importance: Given the rising prevalence of patients with dementia and those at risk for it, early identification is prioritized. As vestibular dysfunction is associated with Alzheimer's disease (AD) and may contribute to its onset, vestibular assessment may yield an opportunity in early dementia screening.

Objective: This systematic review structures and compares the different raw outcome measures used to assess vestibular function while comparing older adults with preserved cognition to individuals with cognitive impairment, either suffering from mild cognitive impairment (MCI) or AD.

Design: Two investigators independently and systematically searched publications performing objectively measured vestibular testing in a patient population consisting of either MCI or AD, compared with a control group of older adults with preserved cognition. No limitations regarding language or publication date were applied. References of the retrieved articles were hand searched for relevant articles.

Results: Seven articles were included for analysis. A total of 235 older adults with impaired cognition (150 AD, 85 MCI) were compared with a control group of 481 older adults with preserved cognition. Evaluation of the peripheral vestibular function included video head impulse test (vHIT), videonystagmography (VNG), electronystagmography (ENG) including bithermal caloric irrigation and vestibular evoked myogenic potentials (VEMP). The VEMP test, assessing otolith function and the elicited vestibulocollic reflex (VCR), was able to differentiate subjects with AD and its prodromal stage from healthy controls, with p13 latency (<0.05) and amplitude (p < 0.05) having the most discriminating power. No correlation between cognitive decline and vestibulo-ocular reflex measurements in different frequency ranges of the semicircular canals (using vHIT, rotatory chair testing, and caloric irrigation) was found. Because of the limited number of available studies and the large heterogeneity in outcome measures, these results have to be interpreted with caution.

Conclusions: Measurements of the VCR, as evoked by the VEMP test, discriminate between patients with cognitive impairment (MCI and AD) and older adults with preserved cognition, whereas measurements of the vestibulo-ocular reflex do not. More studies are needed to further elaborate on these findings.

Key words: Alzheimer's disease, Cognitive decline, Mild cognitive impairment, Vestibular function tests, Video head impulse test, VEMP.

Abbreviations: AD = Alzheimer's disease; MCI = mild cognitive impairment; vHIT = video head impulse test; VNG = videonystagmography; ENG = electronystagmography; VEMP = vestibular evoked myogenic potentials; VCR = vestibulocollic reflex; PRISMA = Preferred Reporting Items for Systematic reviews and Meta-Analyses; NIA-AA = National Institute on Aging-Alzheimer’s Association workgroups on diagnostic guidelines for AD; NINCDS-ADRDA = National Institute of Neurological and Communicative Disorders and Stroke and the AD and Related Disorders Association; MMSE = mini-mental state examination; cVEMP = cervical vestibular evoked myogenic potentials; oVEMP = ocular vestibular evoked myogenic potentials; VOR = vestibulo-ocular reflex; VN = vestibular nuclei; ABD = Abducens nucleus; UHV = unilateral vestibular hypofunction; HC = healthy controls; IWG = International Working Group.

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KEY POINTS

Question: Which outcomes of which vestibular tests can demonstrate a difference between older adults with MCI, AD, and preserved cognition?

Findings: In this systematic review, the cVEMP test demonstrated its potential in distinguishing MCI or AD from older adults. Especially p13 latency and amplitude were the most promising parameters, compared with nondiscriminatory measures of semicircular canal function. Since the search returned a limited number of results, more studies are needed to elaborate these findings.

Meaning: The VEMP test can discriminate between patients with cognitive impairment and preserved cognition. Measurements of the vestibulo-ocular reflex cannot.

INTRODUCTION

As the world’s population increases in age, a growing number of people are affected by dementia. Worldwide around 47 million people suffered from dementia in 2015, and this number is expected to triple by 2050 (Livingston et al. 2017). The most common cause of dementia is Alzheimer’s disease (AD), which accounts for up to seventy percent of all dementia cases, according to the World Health Organization (2019). It is characterized by an episodic memory deficit and evolves from an intermediate state of cognitive decline, more specifically mild cognitive impairment (MCI). Patients with MCI do not experience deficits in their activities of daily living, whereas patients with AD do. When including biomarkers in the diagnosis, the terms prodromal AD or MCI due to AD and dementia due to...
AD should be used instead of the more general terms such as MCI and AD, respectively. For clear writing purposes, both MCI and prodromal AD groups will be described as “MCI,” and for both AD and dementia due to AD, the term “AD” will be used.

Recent evidence suggests that vestibular dysfunction is associated with AD and may contribute to its onset (Schautzer et al. 2003; Brandt et al. 2005; Previc 2013; Bigelow & Agrawal 2015; Semenov et al. 2016). This vestibular loss hypothesis, as described by Previc (2013), is substantiated by the evidence that vestibular decline is associated with hippocampal atrophy, which is an important biomarker for AD (Brandt et al. 2005; Previc 2013; Smith 2016; Allen et al. 2017; Halliday 2017). Furthermore, impaired spatial cognition is among the most frequently observed cognitive deficits in AD (Bird et al. 2010; Bigelow et al. 2015) and is related to vestibular loss (Schautzer et al. 2003; Xie et al. 2017; Wei et al. 2018).

Moreover, recent studies found evidence of impaired spatial cognition in subjects with bilateral vestibulopathy (Schautzer et al. 2003; Kremmyda et al. 2016; Dobbels et al. 2019a, b). In addition, age-related degeneration of vestibulolimbic and -cortical pathways could influence the development of AD (Previc 2013; Smith 2013). Given the rising prevalence of dementia, an emphasis should be put on early treatment.

The aim of this study is to systematically review the literature on vestibular function testing in populations consisting of adults older than 55 years with preserved cognition, MCI, and AD (Gallacher et al. 2012).

**MATERIALS AND METHODS**

This systematic review is performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Moher et al. 2009). The protocol was registered at the PROSPERO international prospective register of systematic reviews (PROSPERO ID: 180620).

**Eligibility Criteria**

- Participants: Patients with diagnosed MCI or AD.
- Comparator: The control group consisted of older adults with preserved cognition.
- Outcomes: Assessment of peripheral vestibular function using functional tests designed to objectively evaluate vestibular function. Results must be quantifiable. Studies reporting on stabilometry, performance-based measurements, subjective assessments, drug trials, or treatment effects were excluded.
- No restrictions were imposed regarding language or publication date.

**Search Strategy**

The search query was defined and ran in the databases of PubMed, Cochrane, Web of Science, and Scopus on November 4, 2020. The following search string was used: (vestibul*) AND (dementia OR Alzheimer OR mild cognitive impairment). References of relevant articles were hand searched for additional papers. Reviews on vestibular assessment in older adults with cognitive impairment were also searched for relevant articles.

The selection procedure consisted of a thorough search on title and abstract first and second on full text. Two investigators (JB and CJ) independently searched publications. Discrepancies were discussed until consensus was reached. All steps of the screening procedure are presented in Figure 1.

The following information was extracted from included articles: author, year of publication, demographic characteristics, in- and exclusion criteria, population sample sizes, results of vestibular function tests, and raw data of outcome measures. Risk of bias was assessed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Institutes of Health 2014), designed by the National Institutes of Health.

**RESULTS**

Electronic database searching resulted in 457 records. After applying eligibility criteria (Fig. 1), seven studies were selected for inclusion, all written in English, reporting on 235 patients with cognitive impairment (85 MCI, 150 AD). These studies all compared vestibular assessments in patients with MCI and AD with older adults with preserved cognition, consisting of 481 controls. Previous research elaborated on the vestibular loss hypothesis (Previc 2013; Smith 2013) or described ways to assess and interpret vestibular contributions to cognitive domains (Li et al. 2014; Palla & Lenggenhager 2014). To our knowledge, this is the first systematic review on vestibular function testing in a population with cognitive impairment as compared to cognitively healthy older adults.

Baydan et al. (2020) performed VNG in 10 patients with MCI and 10 controls (Baydan et al. 2020). Birdane et al. (2012) performed cervical vestibular evoked myogenic potential (cVEMP) in 10 patients with MCI, 20 patients with AD, and 30 controls (Birdane et al. 2012). Chong et al. (1999) performed rotatory chair testing in 11 patients with AD and 17 controls (Chong et al. 1999). Harun et al. (2016) performed cVEMP, ocular VEMP (oVEMP), and vHIT in 15 patients with MCI, 32 patients with AD, and 94 controls (Harun et al. 2016). Micarelli et al. (2018) performed vHIT in 24 patients with MCI, 24 patients with AD, and 23 controls (Micarelli et al. 2018). Nakamagoe et al. (2015) performed bithermal caloric irrigation in 12 patients with AD and 12 controls (Nakamagoe et al. 2015). Wei et al. (2019) performed cVEMP, oVEMP, and vHIT in 26 patients with MCI, 51 patients with AD, 102 controls matched with the MCI patients, and 193 controls matched with the AD patients (Wei et al. 2019).

Different studies identified their patient groups based on different diagnostic criteria, as presented in Table 1 (see Table, Supplemental Digital Content 1, http://links.lww.com/EANDH/A818, which demonstrates an overview of included populations). In one study (Baydan et al. 2020), the diagnosis of MCI was made according to the Petersen criteria (Petersen et al. 2001). In four studies (Nakamagoe et al. 2015; Harun et al. 2016; Micarelli et al. 2018; Wei et al. 2019), the diagnosis of MCI or AD was made according to National Institute on Aging-Alzheimer’s Association workgroups on diagnostic guidelines for AD (NIA-AA) criteria (Albert et al. 2011; McKhann et al. 2011). In two studies (Chong et al. 1999; Birdane et al. 2012), the criteria of the National Institute of Neurological and Communicative Disorders and Stroke and the AD and Related Disorders Association (NINCDS-ADRDA) were used.
(McKhann et al. 1984). When comparing diagnostic criteria of Petersen, NIA-AA and NINCDS-ADRDA for MCI and AD (McKhann et al. 1984; Petersen et al. 2001; Albert et al. 2011; McKhann et al. 2011), most criteria were comparable. The NIA-AA criteria are the revised version of the widely used NINCDS-ADRDA criteria, with in addition the use of biomarkers. McKhann et al. (2011) stated that all patients who were diagnosed with AD according to the NINCDS-ADRDA criteria would also meet criteria for AD according to NIA-AA (McKhann et al. 2011).

Baydan et al. (2020) and Birdane et al. (2012) did not adjust statistical methods for age, whereas all other studies did (Birdane et al. 2012; Baydan et al. 2020). Furthermore, the study by Chong et al. (1999) was the only study that did not perform the MMSE in the control group (Chong et al. 1999). In addition, Chong et al. (1999) and Nakamagoe et al. (2015) did not ascertain the normal cognitive state of the control group by formal neuropsychological testing (Chong et al. 1999; Nakamagoe et al. 2015). Whether Harun et al. (2016) and Wei et al. (2019) performed formal neuropsychological testing in their control group remains unclear (Harun et al. 2016; Wei et al. 2019).

Quality Assessment

Quality assessment was performed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Institutes of Health 2014). This checklist, designed by the National Institutes of Health, evaluates potential flaws in observational cohort and cross-sectional studies, such as sources of bias and confounding variables. All seven studies were prospective cross-sectional studies and were rated as of “good” or “fair” quality, ranging between quality assessment scores of 8 and 10, which can be seen in Table 1 (see Table, Supplemental Digital Content 1, http://links.lww.com/EANDH/A818, which demonstrates an overview of included studies and its quality assessment scores). This means that included studies are possibly susceptible to some bias, but results are considered to be valid. No significant risks of bias were found. None of the included studies assessed vestibular function longitudinally.

Publication Bias

Publication bias cannot be assessed due to the high heterogeneity in outcome measures of included studies.

Vestibular Function Test Results

General Results • The first noteworthy finding is that the search resulted in a small number of articles that fitted all eligibility criteria. Furthermore, the seven included articles reported on a large heterogeneity of outcome measures, which impedes comparison and makes it difficult to draw conclusions.
Harun et al. (2017) investigated the level of cognitive function required to complete standard vestibular tests (Harun et al. 2017). They suggested a threshold of cognitive impairment, more specifically a Mini-Mental State Examination (MMSE) score of 12 or less, which characterizes individuals who are too cognitively impaired to complete vestibular testing (Folstein et al. 1975). The patient population of three studies included MMSE-scores which were all greater than 12, implying that these patients should all be able to complete vestibular assessment (Nakamagoe et al. 2015; Micarelli et al. 2018; Baydan et al. 2020). Harun et al. (2016) included patients with a MMSE-score greater than 10, of which two patients (MMSE of 12 and 12) were unable to follow vestibular testing instructions (Harun et al. 2016). Birdane et al. (2012), Chong et al. (1999), and Wei et al. (2019) included patients with MMSE-scores less than 12 (Chong et al. 1999; Birdane et al. 2012; Wei et al. 2019). This calls into question whether these participants could adequately follow instructions for vestibular testing. Therefore, these results must be interpreted with caution. An overview of main outcome measures and its statistical significance is provided in Table 2 (see Table, Supplemental Digital Content 2, http://links.lww.com/EANDH/A819, which demonstrates an overview of main outcome measures of included studies).

**Vestibular Physiologic Function Results**

**Cervical VEMP and Ocular VEMP** • Birdane et al. (2012), Harun et al. (2016), and Wei et al. (2019) used the cVEMP and oVEMP to assess vestibular function (Birdane et al. 2012; Harun et al. 2016; Wei et al. 2019). cVEMPs are measurements of saccular function using electromyographic activity of the contracted sternocleidomastoid muscle contralateral from the auditory stimulated ear. The cVEMP test is performed while patients lie in the supine position. A typical cVEMP tracing consists of a biphasic waveform, showing two distinctive peaks (p13, n23) (Li et al. 2014; Rosengren et al. 2019). Outcome measures are the latencies of p13 and n23 and their amplitude. The prevalence of bilaterally absent cVEMPs are recorded, which is marked when the characteristic waveform was missing (Birdane et al. 2012; Harun et al. 2016). Wei et al. (2019) marked abnormal vestibular function as abnormal when function was unilaterally or bilaterally absent (Wei et al. 2019).

OcVEMPs measure utricular function using vibration-evoked extraocular myogenic responses. A typical oVEMP potential is also biphasic and characterized by two distinctive peaks (n10, p16) (Li et al. 2014). Outcome measure is the amplitude of the eye with better vestibular function and abnormal oVEMPs (Harun et al. 2016; Wei et al. 2019). Both Birdane et al. (2012) and Harun et al. (2016) found the amplitude to be significantly (p < 0.05) decreased in patients with cognitive impairment compared with healthy controls (Birdane et al. 2012; Harun et al. 2016). A smaller amplitude was associated with increased odds of AD (Harun et al. 2016). Harun et al. (2016) reported no significant difference in amplitude between healthy controls and patients with MCI (Harun et al., 2016).

In contrast, results provided by Birdane et al. (2012) demonstrated no statistically significant difference in amplitude when comparing patients with MCI to patients with AD but rather a discrepancy between patients with cognitive impairment and older adults with preserved cognition (p < 0.05) (Birdane et al. 2012). Furthermore, they demonstrated that a prolonged p13 latency was associated with cognitive impairment (p < 0.05), where n23 latency was not (Birdane et al. 2012). In addition, patients with AD had a significantly higher prevalence of bilaterally absent or abnormal cVEMPs compared with controls (p ≤ 0.01) (Harun et al. 2016; Wei et al. 2019). According to Wei et al. (2019), patients with MCI had a significantly higher prevalence of abnormal cVEMPs and oVEMPs compared with controls (p < 0.05). However, this difference is less outspoken than the prevalence of abnormal cVEMPs and oVEMPs in AD patients in comparison to controls (p < 0.001) (Wei et al. 2019). Harun et al. (2016) stated that bilaterally absent cVEMPs increased the odds of AD by over three times. Harun et al. (2016) controlled for adequate contraction of the sternocleidomastoid muscle during cVEMP testing, whereas Birdane et al. (2012) and Wei et al. (2019) did not, which calls the validity of these results into question.

**Vestibulo-ocular Reflex** • Harun et al. (2016), Micarelli et al. (2018), and Wei et al. (2019) used the vHIT (Halmagyi et al. 2017) to assess vestibulo-ocular reflex (VOR) gain by horizontally rotating patients’ heads with a small amplitude and high velocity to stimulate the horizontal semicircular canals (Harun et al. 2016; Micarelli et al. 2018; Wei et al. 2019). Only Wei et al. (2019) demonstrated a significant difference in VOR gain between MCI and controls (p = 0.008); however, this difference was absent between AD and controls. Both other studies did not find a significant difference in VOR gain between controls, MCI, and AD. Chong et al. (1999) confirmed these results by using the rotary chair to measure VOR gain (Chong et al. 1999). During this test, subjects’ eye movements were recorded while a moveable chair rotated from side to side. This measurement was performed in the dark as well as with lights on. Baydan et al. (2020) also confirmed these results by using VNG. Using goggles with a built-in camera, they recorded eye movements during saccadic and smooth pursuit, as well as spontaneous nystagmus. They found no significant differences in overall VOR between MCI and controls. They measured VOR by comparing the right and left saccade peak velocity, accuracy, and latency between MCI and controls, of which none were statistically significant (p > 0.05) (Baydan et al. 2020).

**Caloric Response and Visual Suppression** • To induce caloric nystagmus, patients experience bithermal caloric irrigation in each ear sequentially. Nakamagoe et al. (2015) reported no significant difference in nystagmus parameters of caloric stimulation before and during visual suppression between older adults with cognitive impairment or preserved cognition. Only the suppression rate was significantly lower in patients with AD, compared with age-matched controls (p = 0.022) (Nakamagoe et al. 2015).

**DISCUSSION**

This study aimed to systematically review the literature on vestibular function testing in populations of older adults with preserved cognition, MCI and AD. The search resulted in seven included studies reporting heterogeneous outcome measures.

Overall, a higher prevalence of vestibular loss has been observed among individuals with cognitive impairment relative to older controls with preserved cognition. Supporting evidence demonstrated a balance decline when aging, being more pronounced in individuals with MCI (Pettersson et al. 2002, 2005; Liu-Ambrose et al. 2008; Shin et al. 2011; Nascimbeni et al. 2015) and even greater in individuals with AD (Jensen et al. 2003; Leandri et al. 2009). More precisely, this simultaneous
presentation of cognitive impairment and a decline in balance appears to be associated with loss of otolith function, as measured by c- and oVEMP for saccular and utricular function, respectively, hence involving the VCR. On the other hand, the VOR—resulting from semicircular canal stimulation—, as measured by rotatory testing, bithermal caloric irrigation, and vHIT, is mainly preserved (Harun et al. 2016). Therefore, VEMPs could be the most promising outcome measure related to vestibular function in discriminating between AD and its prodromal stage. More specifically, p13 latency and amplitude are the parameters of interest. In contrast, measures of semicircular canal function are generally not different in patients with normal or impaired cognition. In addition, the suppression rate during visual suppression of the caloric nystagmus also showed a significant differentiation between AD patients and healthy controls. This may indicate parietal lobe dysfunction due to AD and decreased blood flow in the inferior parietal lobule. Furthermore, a lower suppression rate was associated with a higher tendency to fall in patients with AD (Nakamagoe et al. 2015).

The VEMP test has plenty of advantages for utilization in clinical practice. It is noninvasive, reliable, and safe. However, some factors may influence its results, such as muscle weakness, obesity, and age. For example, 5 to 15% of individuals older than 60 years demonstrated absent cVEMP responses (Rosengren et al. 2019). Furthermore, results could be operator dependent, as no fixed criteria for the tracings exist, and interpretation may be complicated.

To explain why otolith function declines with cognitive impairment, while semicircular canal function is preserved, one may look at underlying neuronal pathways. Vestibular afferents transfer vestibular information to the vestibular nuclei, which are connected to multiple brain areas, including the contralateral vestibular nuclei, the abducens nucleus (ABD)—responsible for VOR production—, higher brain centers involved in cognitive processing (such as spatial orientation), and the spinal cord motor neurons that produce the vestibulospinal reflex to maintain posture (Fig. 2) (Cullen 2012; Hitier et al. 2014). Considerable evidence exists that neurons in the VN that project to motoneurons involved in the VOR, are distinct from those which transmit vestibular information to higher brain areas, as they do not ascend to the thalamus and do not project cortically (Cullen 2012; Smith 2013; Harun et al. 2016). Neurons in higher brain structures that respond to vestibular stimulation are insensitive to eye movement, further supporting a segregation between pathways to higher areas of the brain and pathways involved in the VOR (Smith 2013; Smith & Zheng 2013). However, Harun et al. (2016)

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**Fig. 2.** Neuronal pathways involved in transmitting vestibular information. Vestibular afferents project to the brainstem vestibular nuclei. These vestibular nuclei project to higher brain structures, eye muscles, and spinal cord muscles. ABD, abducens nucleus; VCR, vestibulocollic reflex; VOR, vestibulo-ocular reflex; VN, vestibular nuclei; VSR, vestibulospinal reflex.
propose a hypothesis why the VCR decreases simultaneously with cognitive decline, whereas the VOR remains intact. They hypothesize that vestibular—specifically saccular (Miyamoto et al. 2007; Schlindwein et al. 2008)—projections to the higher brain structures undergo anterograde degeneration in cognitive impairment, resulting in an impaired VCR (Harun et al. 2016). These patients also suffer from profound deficits in spatial awareness and spatial memory but do not exhibit VOR deficits, as these distinct pathways would be left intact (Smith 2013). Therefore, a failure in finding VOR deficits in patients with cognitive impairment does not contradict the vestibular loss hypothesis as described by Previc (Lakshminarayanan et al. 1986; Previc 2013; Smith 2013). Would VOR changes still be observed, they would mainly be due to physiological aging (Nakamagoe et al. 2015). One must keep in mind that otothlith-cervical and otothlith-ocular projections that underlie the VEMP responses are distinct from the otothlith-cortical projections (Harun et al. 2016).

An additional explanation for the observed association between vestibular dysfunction and cognitive impairment includes the hypothesis of a “spatially impaired” subtype of AD. This specific subtype can be characterized by spatial disorientation and impaired spatial navigation, with symptoms such as losing or misplacing objects, driving difficulty, wandering, and falls (Hamilton et al. 2009; Cipriani et al. 2014; van der Wardt et al. 2015; Wei et al. 2017). Wei et al. (2018) observed a significantly higher prevalence of vestibular loss in patients with “spatially impaired” AD, supporting this hypothesis (Wei et al. 2018). The rationale behind this hypothesis of a specific “spatially impaired” subtype of AD is comparable to the vestibular loss hypothesis posited by Previc (2013). It focuses on the loss of vestibular (in particular saccular) input, leading to neurodegeneration of spatial processing networks, including the hippocampus (Agrawal et al. 2020). Therefore, in these patients, vestibular loss would impair specifically spatial cognition, independently of the more general cognitive decline associated with AD (Wei et al. 2018).

Balance impairment can also be assessed using stabilometry and gait analysis. Stabilometric results in patients with AD have demonstrated difficulties in maintaining balance while concurrently having to suppress incongruent visual and somatosensory information (Liu-Ambrose et al. 2008; Leandri et al. 2009; Shin et al. 2011; Micarelli et al. 2018), even in case of normal peripheral vestibular function (Chong et al. 1999). Studies on gait analysis show a greater than expected balance impairment in patients with AD (Pettersson et al. 2002; Pettersson et al. 2005; Nakamagoe et al. 2015; Micarelli et al. 2018). Gait disorders are not only more prevalent in dementia compared with normal aging, they are also related to the severity of cognitive decline (O’Keeffe et al. 1996; Beauchet et al. 2008; Gras et al. 2015). As such, patients with AD show a decreased walking speed and disturbances in dual-tasks, with the latter possibly being a specific marker of falling at a preclinical dementia stage (Pettersson et al. 2005; Beauchet et al. 2008), although contradictory results exist (Nascimento et al. 2015). Studies reporting on stabilometry or gait analysis were not included in this review as they do not specifically assess vestibular dysfunction.

Hearing loss, affecting around a third of the older population, is independently associated with dementia (Lin 2011; Lin et al. 2011a, b; Gallacher et al. 2012; Fritze et al. 2016; Deal et al. 2017). Furthermore, hearing loss has been recognized as one of the most important modifiable risk factors for dementia (Livingston et al. 2017). Vestibular decline, however, is often overlooked as a potential concomitant risk factor for dementia (Cushing et al. 2008; Jacot et al. 2009; Semenov et al. 2016; Loughrey et al. 2018). Within vestibular research, data on hearing level are generally lacking (Dobbels et al. 2019b). This trend is also present in included studies. Three studies failed to mention any kind of audiological assessment (Chong et al. 1999; Nakamagoe et al. 2015; Harun et al. 2016). One study excluded patients with hearing loss because of a possible false negative in VEMP responses (Birdane et al. 2012), and one study performed pure-tone audiometry but did not report on audiologic outcomes or findings (Micarelli et al. 2018). Some recent studies investigating vestibular function and cognitive impairment did control for hearing loss. Evidence shows that cognitive impairment related to vestibular loss cannot be fully explained by hearing loss (Bigelow et al. 2016; Kremmyda et al. 2016; Semenov et al. 2016).

Given the limited number of included studies, the significant heterogeneity of outcome measures, and the heterogeneity with regard to inclusion criteria (use of biomarkers, formal neuropsychological testing of controls), further research is required to establish the association between vestibular function tests and cognitive impairment, with inclusion of the assessment of hearing levels. In addition, the evaluation of anxiety should also be assessed, as this is a common problem in patients with vestibular impairment (MacDowell et al. 2018), could contribute to cognitive dysfunction (Gulpers et al. 2019), and is frequently overlooked. Indeed, none of the included studies evaluated participants’ level of anxiety. Statistical methods should be adjusted for age, which is crucial when comparing vestibular, hearing and cognitive function, as all decline with age (Iwasaki & Yamasoba 2015; Fischer et al. 2016). As current International Working Group-2 criteria, a refined and simplified diagnostic framework involving the use of biomarkers in the diagnosis of AD, can quite reliably diagnose AD and MCI (Dubois et al. 2014) evaluation of peripheral vestibular function might allow for early detection of at-risk individuals. Furthermore, the potential treatment or rehabilitation of vestibular dysfunction might slow or even reverse cognitive decline. However, there is a need for longitudinal studies. Thus, even when vestibular function testing has shown promising results, further research is encouraged.

**CONCLUSION**

Measurements of the VCR, using the VEMP test, may suggest a discrimination between patients with cognitive impairment (MCI and AD) and older adults with preserved cognition, whereas measurements of the VOR, using vHIT or ENG, may not. Given the heterogeneity of VEMP testing and the small number of included studies, more studies are needed to corroborate these findings. Furthermore, more studies on vestibular function testing in older adults with and without cognitive impairment, including the assessment of hearing function and anxiety, are needed.

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