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Review

Peripheral vestibular system: Age-related vestibular loss and associated deficits

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ABSTRACT

Given the interdependence of multiple factors in age-related vestibular loss (e.g., balance, vision, cognition), it is important to examine the individual contributions of these factors with ARVL. While the relationship between the vestibular and visual systems has been well studied (Bronstein et al., 2015), little is known about the association of the peripheral vestibular system with neurodegenerative disorders (Cronin et al., 2017). Further, emerging research developments implicate the vestibular system as an opportunity for examining brain function beyond balance, and into other areas, such as cognition and psychological functioning. Additionally, the bidirectional impact of psychological functioning is understudied in ARVL. Recognition of ARVL as part of a multifaceted aging process will help guide the development of integrated interventions for patients who remain at risk for decline. In this review, we will discuss a wide variety of characteristics of the peripheral vestibular system and ARVL, how it relates to neurodegenerative diseases, and correlations between ARVL and balance, vision, cognitive, and psychological dysfunction. We also discuss clinical implications as well as future directions for research, with an emphasis on improving care for patients with ARVL.

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1. Introduction

1.1. The vestibular system

The vestibular system is involved in maintaining balance and orientation in space by sensing head movement and coordinating eye and postural movements. The vestibular organ, located in the inner ear, contains a membranous labyrinth composed of three semicircular canals and two otolith organs, all of which are filled with endolymph (Jones et al., 2009). Each semicircular canal contains an ampulla, which consists of hair cells with stereocilia embedded onto a gelatinous mass known as the cupula. In the otolith organs, the utricle and saccule, the hair cell stereocilia are embedded onto an otolith mass (Casale and Gupta, 2018). The utricle and saccule are responsible for sensing linear acceleration, while the semicircular canals are involved in sensing angular acceleration (Highstein and Holstein, 2012). During rotational or linear acceleration, the cupula or otolith mass displace the hair cells, respectively, causing depolarization or hyperpolarization (Yoo and Mihaila, 2020). The vestibulocochlear nerve receives input from the hair cells and terminate at the vestibular nuclei in the medulla (Purves et al., 2001). The vestibular nuclei project onto the brain stem, cerebellum, spinal cord motor neurons, and extraocular muscle nuclei, which orients the eyes and body according to head movement (Hitier et al., 2014).

We are able to maintain a clear image during head movement via the vestibulo-ocular reflex (VOR). Sensory information from the vestibular organ reach the vestibular nuclei via afferent fibers (Hitier et al., 2014). Efferent fibers from the vestibular nuclei supply nerves III, IV, and VI, innervating the extraocular muscles (Yoo and Mihaila, 2020). When the head moves horizontally, the eyes move in the opposite direction, allowing for a stable gaze (Bronstein et al., 2015). VOR gain is a value that determines the difference between the eyes and corresponding head movement amplitudes (Hirvonen et al., 2000). This measure, as well as other VOR tests, can be used clinically to measure peripheral vestibular function (Figtree et al., 2020; Simakurthy and Tripathy, 2020). Changes in VOR can be associated with aging and other signs of vestibulopathy, including unsteady gait, motion sickness, nausea, and difficulty maintaining balance (Somisetty, 2019). A dysfunctional vestibular organ will send the brain mixed signals about head motion, causing vertigo (Somisetty, 2019).

While the relationship between the vestibular and visual systems has been well studied (Bronstein et al., 2015), little is known about the association of the vestibular system with neurodegenerative disorders (Cronin et al., 2017). Neurodegenerative diseases and vestibulopathy are both associated with increasing age, and signs of vestibular loss are commonly seen in neurodegenerative diseases. Moreover, a higher incidence of falls is seen in patients with Alzheimer's and Parkinson's disease (Farombi et al., 2016; Perttila et al., 2017) when compared to age-matched controls, suggesting a correlation between vestibular loss and neurodegeneration. Detecting vestibular dysfunction may play an important role in the diagnosis of neurodegenerative disorders in the initial stages.

1.2. Vestibular function in neurodegenerative diseases

1.2.1. Vestibular loss in Alzheimer's disease

The vestibular system is composed of the peripheral vestibular organs and associated central nervous system projections. Therefore, vestibular signals are often found in association with other sensory and motor signals, and impairment of their processing may constitute the balance disorders and spatial disorientation commonly found in neurodegenerative diseases. Application of the vestibular system in the study of neurodegenerative disorders could also be relevant since the vestibular system is one of the oldest sensory systems (James, 1950), the earliest to develop in utero (Nandi and Luxon, 2008), and degeneration of phylogenetically older neurons has been found in Alzheimer's disease (AD; Lyness et al., 2003). With an increasing elderly population, a rise in vestibular impairment and neurodegenerative diseases are expected to reach unprecedented levels. Therefore, there will be an increased need for more aggressive strategies directed at identifying early biomarkers that might offer potential for preventing or at least slowing this impending neurologic crisis. Detecting dizziness and imbalance, as well as other specific vestibular testing, may have an important etiological role in the early diagnosis of neurodegenerative disorders, as well as offer potential for early interventions that could possibly mitigate neuronal degeneration.

Alzheimer's disease is a progressive neurodegenerative disorder distinguished by beta-amyloid plaques and neurofibrillary tangles in the brain. Despite imbalance being underrecognized as a clinical manifestation of AD (Leandri et al., 2009; Nakamagoe et al., 2015), AD and preclinical patients are more likely to fall (Stark et al., 2013; Perttila et al., 2017) and have a higher rate of fractures (Buchner and Larson, 1987). In addition, AD subjects have been shown to body sway during quiet standing, which was more severely altered with closed eyes and with patients with lower cognitive scores (Leandri et al., 2009). Patients have also exhibited a likelihood to turn than stay in the same position in an eyes-closed stepping test, suggesting that balance impairment could potentially be a leading cause of AD-related falls (Nakamagoe et al., 2015).

The hippocampus, a brain region involved in spatial orientation (Maguire et al., 1997), is one of the earliest areas to degenerate in brains of patients with AD (Braak and Braak, 1991). Moreover, patients with bilateral vestibular loss demonstrate a correlation between hippocampus atrophy and low performance of spatial memory tasks (Brandt et al., 2005). This discovery suggests that peripheral vestibular loss may be a causative agent of AD via anterograde degeneration, starting with a lower structure, such as a vestibular organ, followed by its higher structures, such as vestibular projections and the hippocampus (Previc, 2013). Epidemiological studies should be conducted in order to identify peripheral vestibular loss as a risk factor for AD.

1.2.2. Vestibular loss in Parkinson's disease

Parkinson's disease (PD), which has an incidence rate that rapidly increases over the age of 60 (Van Den Eeden et al., 2003; Tysnes and Storstein, 2017), has been shown to produce postural instability which significantly disrupts quality of life. Patients with PD have been shown to have a reduced limit of stability area and increased postural sway (Doná et al., 2016). Postural instability, shown to be affected by the patient's diminished ability to process vestibular information, has been linked to a major risk of falls. Moreover, the issue of postural control is more related to the inability to perceive movement compared to the inability to generate movement. PD patients have also been shown to have a compromised processing of vestibular information via a sensory organization test (Colnat-Coulbois et al., 2011; Rossi-Izquierdo et al., 2014), regardless of their stage in the course of PD (Rossi et al., 2009). Furthermore, alteration of proprioception in individuals with PD resulted in no reevaluation of vestibular signals, unlike in healthy individuals. This suggests that the lack of postural control in PD could potentially be due to the inability to sense movement rather than the inability to generate movement properly (Hwang et al., 2014, 2016).

Vestibular and optic signals are integrated in the cingulate sulcus visual area (Cardin and Smith, 2010), which has been shown to have reduced neuronal activity with increased disease severity (Putcha et al., 2014). Moreover, vestibular-evoked myogenic potential responses in individuals with PD has been demonstrated to be abnormal when compared to healthy controls (Pollak et al., 2009; De Natale et al., 2015; Venhovens et al., 2016) and to have a correlation with severity of bradykinesia, ipsilateral dyskinesia, contralateral rigidity, sleep, mood, and memory impairment (Shalash et al., 2017). Also, pathological changes have been found in PD vestibular nuclei (Seidel et al., 2015) and their connection with the dorsal raphe nuclei (Halberstadt and Balaban, 2007). Furthermore, the PD vestibular nuclei have been shown to have a reduced response to dopamine (Pötter-Nerger et al., 2012). Importantly, mood disorders are very common in all PD patients, with 40–50% meeting criteria for clinical depression (Marsh, 2013).

1.3. ARVL and associated dysfunction

1.3.1. Peripheral vestibular changes in aging

Vestibular disfunction is common in the normal aging process. One study of 740 individuals over 65 presenting for otologic evaluation found that 21% of the individuals had identifiable causes of dizziness and 79% had progressive disequilibrium of aging (Belal et al., 1986). The primary changes in the peripheral vestibular system in the aging process are the loss of neurons and hair cells in both the otolith organs and semi-circular canals (Rauch et al., 2001). Aging is associated with histopathological changes including progressive degeneration of hair cells, otoconia in otolith organs, and Scarpa's ganglion neuronal degeneration (Rauch et al., 2001). The sensory epithelial morphology undergoes age-induced changes, including an accumulation of lipofuscin granules and lysosomes, and changes in the hair bundles, such as disarrangement and loss of stereocilia and kinocilia, formation of giant cilia, and increased fragility of cilia (Rosenhall and Ruben, 1975; Nakayama et al., 1994). Rauch et al. demonstrated hair cell loss in 67 temporal bone samples from 49 individuals aged 1–100 years. They demonstrated a constant and statistically significant decrease with age, fit by a linear regression model (Rauch et al., 2001). Morerecent studies have demonstrated that synaptic loss may be an early and major contributor in ARVD (Wan et al., 2019). While the mechanism behind this synaptopathy is unknown, it is hypothesized that constant stimulation of the sensory system may lead to hyperexcitability eventually harming the synapses (Wan and Corfas, 2015). As hair cells and neurons do not undergo regeneration in humans, these losses are permanent.

1.4. Balance

The vestibular system plays a large role in maintaining balance (Khan and Chang, 2013). It is also well documented that vestibular function declines with age, and is associated with deficits in gait, unsteadiness, increased risk of falls, and impairments in emotional functioning (Tinetti et al., 2000; Agarawal et al., 2009, 2013; Xie et al., 2017). In fact, vestibular loss, particularly loss involving horizontal semicircular canal function, has been directly linked to slower gait speed (Anson et al., 2019). Data from the National Health and Nutrition Examination Survey (NHANES) indicates a high prevalence of difficulties with vestibular function among the elderly, with 69% among those aged 70–79 years and 85% among those aged 80+ years having vestibular dysfunction (Agrawal et al., 2009). Additionally, as discussed earlier in this review, balance problems are seen in neurodegenerative diseases associated with aging, such as, PD and AD. Furthermore, Harun and colleagues, reported that all patients in their study examining age-related vestibular loss, reported difficulty walking (Harun et al., 2016).

Fall risk is an important factor related to ARVL, as falls is the 7th leading cause of deaths in the elderly (above 65 years of age) in the United States (National Center for Health Statistics, 2017; National Center for Health Statistics, 2021). The NHANES data demonstrated an association between vestibular dysfunction in the elderly and increased risk of falls (Agrawal et al., 2009). Further, in a study comparing age-matched patients who were non-fallers to fallers, the prevalence of elderly adults with a clinically significant vestibular impairment who fell was much larger- 80% vs 18.75% (Liston et al., 2014). This further demonstrates the association between vestibular dysfunction and falls. Moreover, conditions that are age-related and include functional limitations (e.g., visual impairment, arthritis) are predictive of increased fall risk. Thus, this may be an optimal time period to intervene to deter functional limitations (Dunlop et al., 2002).

ARVL and balance dysfunction are related to impairments in emotional functioning (Tinetti et al., 2000; Gazzola et al., 2009). Specifically, Harun and colleagues found that most of their participants reported fear and anxiety, especially related to fear of falling and safety concerns (Harun et al., 2016). This finding is concerning as fear of falling may lead to decreased socialization, which previous research has found to be important to outcomes in the elderly (Steptoe et al., 2013). Additionally, internalizing disorders have been associated with balance dysfunction (Furman and Jacob, 2001). For instance, Jacob, Redfern, & Furman demonstrated that abnormal balance was associated with space and motion discomfort and anxiety (Jacob et al., 2009). Addressing balance dysfunction in relation to ARVL is important not only for physical independence, but also for healthy emotional functioning.

Given the established association between age-related vestibular loss and balance difficulties, it is crucial that clinicians manage balance difficulties, including counseling of fall prevention, in order to best help this population. Furthermore, the elderly population is rapidly increasing, with projections of doubling of the elderly population in the United Stated by 2050, from 48 million to 88 million in 2050 (He et al., 2016). Early intervention and appropriate care can assist with ameliorating the healthcare costs associated with aging and age-related vestibular loss, especially related to emergency room visits which place a large economic burden on the healthcare system (Haddad et al., 2019).

Given that slow gait and impaired walking are linked to frailty, which in turn is associated with both elevated fall risk and cognitive decline, it is possible that timely identification of vestibular dysfunction may offer a path toward developing treatment strategies designed to arrest a cascade of decline leading to increased physical and cognitive vulnerability.

1.4.1. Vision

It is well-established that all sensory systems are adversely affected by degenerative processes associated with aging. As with vestibular and balance impairment, the prevalence of visual impairment (VI) increases with age (Congdon et al., 2004). VI also has comparable, widespread functional consequences that not only deter from successful aging (Swenor et al., 2020), but also contribute to mobility disability and slower walking speeds when compared to their counterparts without VI (Swenor et al., 2013). Additionally, reduced spatial and scotopic contrast sensitivity secondary to aging leads to increased difficulty seeing in dimly lit or dark environments (Owsley, 2011). This physiologic limitation, when compounded with functional limitations and declines in other sensory systems, increases propensity for instability, risk for falls, and consequent injuries – all hallmark concerns regarding older adults with VBI.

VI is most often quantified using diagnostic tests of visual acuity and can be categorized as correctable refractive error or eye disease, which can be irreversible or reversible (e.g., cataracts) with medical/surgical intervention (Swenor et al., 2013). There are tests that assess the vestibulo-ocular reflex (VOR), which stabilizes gaze during locomotion (Leigh and Brandt, 1993), and those that assess the vestibulo-spinal reflex (VSR), which coordinates head and neck movements with the trunk and body so as maintain the head in an upright position and keep one's center of gravity over his/her base of support (Manzoni, 2009). While age-related changes have been reported across a majority of the tests encompassed within the diagnostic vestibular evaluation battery, this section will aim to highlight only those tests that utilize vision (i.e., extra-ocular musculature) to capture functional output of the vestibular system by way of the VOR: videonystagmography (VNG), rotational vestibular testing (RVT), ocular vestibular-evoked myogenic potential testing (oVEMP), and video head impulse testing (vHIT).

Calder (2000) published a thorough summary on the effects of aging seen across tests of oculomotility function, a subset of tests within the VNG battery. Overall, prolonged saccadic latencies and reduced smooth pursuit and optokinetic gains were observed in geriatric populations when compared to younger adults. As a result of these performance deficits in oculomotility function, retinal slip and reduced ability for gaze fixation during head movement are more common among older adults, which increases an individual's likelihood for functional imbalance, postural instability, and ultimately falls (Zalewski, 2015). Per Paige (1992), imbalance may be exacerbated in individuals over 70 years of age when compounded by subtle, age-related VOR deficits and less adaptive central plasticity.

Despite the wide variety of tests available within the RVT battery, effects of aging have been largely examined via sinusoidal harmonic acceleration (SHA) and velocity step/trapezoidal testing. Diminished slow-phase velocity, reduced, low-frequency VOR gain, and increased low-frequency VOR phase leads in SHA were observed in geriatric populations when compared to younger populations (Paige, 1991). Furman and Redfern (2001) noted significantly longer VOR time-decay constants during step-testing in geriatric versus younger populations. This may reflect decrements in central velocity storage function, a mechanism central to compensatory and adaptive processes with the central nervous system following vestibular insult and/or insidious age-related changes. Additionally, Serrador and colleagues observed decrements in ocular counter-roll (OCR) during roll-tilt examinations during RVT in geriatric populations when compared to younger populations (Serrador et al., 2009).

Overall, studies investigating the use of vHIT and oVEMP in aging/geriatric populations are limited. Matino-Soler and colleagues observed notable decreases in VOR gain as age and head impulse velocity decreased (Matiño-Soler et al., 2015). Li and colleagues observed similar findings but noted increased difficulty in obtaining VOR gain greater than 0.80 in patients aged 80 years and older (Li et al., 2015). Consequences of the decrements in VOR function observed with vHIT mirror those of RVT leading to a propensity for retinal slip and reduced ability for gaze fixation during head movement. Poorer physiologic function in turn results in increased likelihood for functional imbalance, postural stability, and greater risk for falls. With regards to oVEMP, Piker and colleagues observed a significant amplitude decrease and threshold increase in the oldest group (>50 years of age) utilized in their study (Piker et al., 2011). Tseng investigated age-related effects on oVEMP testing and noted that responses were increasingly difficult to obtain in individuals aged 60 and older, which may be secondary to utricular buoyancy changes as a result of aging (Tseng et al., 2010). However, difficulty obtaining oVEMP responses may also be confounded by the degree of maximal gaze necessary to provoke the oVEMP response, which is noted to decrease with age or may be restricted due to certain pathologies or physical limitations (Chamberlain, 1971). As such, while reduced and/or absent oVEMP responses may suggest sub-optimal utricular output (which would contribute to increased postural sway, imbalance, and reduced spatial navigation abilities), remarkable findings in oVEMP testing should be interpreted with caution given overall limitations of testing secondary to age.

In summary, adequate maintenance of balance is orchestrated by the timely integration and processing of vestibular, visual, and somatosensory inputs in the central nervous system, which in turn inform outputs to the musculo-skeletal and visual systems to maintain balance (Iwasaki and Yamasoba, 2015). In the presence of insult to any one or multiple sensory systems, sensory reweighting within the central nervous system can help to prioritize more accurate and reliable sensory information over sub-optimal signals to improve maintenance of balance (Peterka, 2002). However, as a result of neuronal cell degradation secondary to aging, integration, processing, and responsiveness of these sensory inputs and outputs are reduced and/or compromised. For example, if an individual has age-related visual deficits that are further compounded by unaddressed VI, peripheral neuropathy secondary to diabetes mellitus, and reduced vestibular end-organ function as a result of age, the central nervous system will struggle to determine which of the three systems it should give priority to for maintenance of balance. However, if VI were to be addressed with corrective lenses and VBI with vestibular rehabilitation therapy/fall prevention program, maintenance of balance could be more successfully mediated by the central nervous system, ultimately making the individual less likely to become imbalanced or unstable and fall. As falls and fall-risk become increasingly important among a growing aging demographic, multi-system measurement should be completed to address the integrated natures of these systems in maintaining postural stability and prolonging the independence of older adults.

1.4.2. Cognitive

There is extensive research describing the link between vestibular loss and ocular motor and postural reflexes (Curthoys and Halmagyi, 1999; Bense et al., 2004). However, emerging research developments implicate the vestibular system as an opportunity for exploring brain function beyond balance, and into other areas, such as cognition (Gurvich et al., 2013). Specifically, Redfern found that patients with unilateral vestibular loss had poor reaction time in four postural conditions and this deficit was even apparent when in the seated position without any sway (Redfern et al., 2004) This indicates a cognitive deficit independent of contribution from vestibular reflexes (Redfern et al., 2004). Cognitive deficits have also been implicated in ARVL. Specifically, Xie et al. found that older adults with vestibular loss performed poorer on a dynamic spatial navigation task compared to both old and young controls (Xie et al., 2017). Additionally, previous research has demonstrated an association between vestibular loss and poor performance on neurocognitive tests of spatial cognition in older patients (Bigelow and Agrawal, 2015). Of particular interest in this study is that the older controls with intact vestibular functioning also had navigational impairments, indicating that another factor (besides clinical vestibular loss) is impacting egocentric navigation. This is important as it suggests there is an association between ARVL and cognition. Another study also demonstrated that older individuals had greater errors in angle rotation estimations on a path integration task (Triangle Completion Task) compared to younger individuals (Adamo et al., 2012).

Other areas of cognition such as memory, attention, and executive functioning have also been associated with vestibular loss (Dos Santos Caixeta et al., 2012; Gurvich et al., 2013; Bigelow et al., 2016). Specifically, Bigelow et al., 2016 found that individuals with vestibular vertigo have more difficulties with memory and confusion than the general population. Further, a study of patients with vestibular loss demonstrated that two thirds of patients displayed cognitive impairment such as, short-term memory loss, difficulties with word retrieval, and inability to prioritize tasks (Black et al., 2004). Executive functioning is also affected by vestibular loss, with one study demonstrating poor executive functioning in patients with vestibular vertigo (Risey and Briner, 1990). Despite these findings in populations with vestibular loss, there is limited research on cognitive deficits specifically related to ARVL. Even less is known regarding the impact of chronic ARVL on cognition over time.

In summary, ARVL affects multiple cognitive domains. ARVL and cognition should be examined in the elderly to further parse out the impact of ARVL on cognition in order to create successful interventions that can assist this growing population with cognitive deficits. Given that declines in cognitive ability are also associated with increased physical vulnerability and frailty, and both are related to poorer psychological functioning, it would be important to routinely screen for ARVL in order to identify points of intervention that may impact overall cognitive and psychological being.

1.4.3. Psychological

How ARVL affects emotion in older individuals is not well understood but there is growing recognition that disruption of vestibular function is connected to reduced psychological wellbeing. In fact, previous literature on vestibular loss (e.g., dizziness, vertigo) has demonstrated an association with psychological factors. Specifically, multiple studies using the NHANES data have demonstrated a link between vestibular loss and poorer health related quality of life (Ward et al., 2013), as well as vestibular vertigo and an increase in depressive and anxious symptoms, and panic disorder (Bigelow et al., 2016).

There is limited research examining ARVL and psychological factors. Harun et al. (2016) reported patients with ARVL endorsed concerns about depression, fear, and anxiety. In particular, patients reported feeling frightened because they didn't know when they were going to have symptoms, a loss of independence, and a lack of feeling safe. Additionally, patients reported embarrassment about stumbling, fear of falling, and depression due to not being able to do things they did before (Harun et al., 2016). Mood disorders are common among the elderly, with the CDC estimating a prevalence of depression of 7.7% and one study finding an 11.19% prevalence rate (Steffens et al., 2009). Aging is often accompanied by a degeneration of physical functioning, such as, hearing and vision loss which have been associated with depression, reduced quality of life, and social isolation, to name a few (Steptoe et al., 2013; Davis et al., 2016). Evidence to support the claim that ARVL further contributes to this cascade of events is supported by literature demonstrating an association between depression and the elderly with vestibular loss (Gazzola et al., 2009). In a sample of the elderly living in a community setting, Tinetti et al. (2000) demonstrated an association between chronic dizziness and depressive symptoms. Similar to hearing loss, it can be posited that patients with ARVL experience social isolation. In fact, Harun et al. (2016) found that patients with ARVL reported attending fewer social activities and over half of patients reported feeling socially isolated. This is of importance given that social isolation is associated with loneliness, which in turn is related to increased mortality, cognitive impairment and other negative health outcomes (Steptoe et al., 2013; Cacioppo and Cacioppo, 2014).

In regard to anxiety disorders and vestibular loss, there is limited research in the elderly population. However, there is a high comorbidity between balance disorders and anxiety, including agoraphobia, panic attack, and generalized anxiety disorder (Alvord, 1991; Balaban and Jacob, 2001; Balaban and Thayer, 2001; Jacob and Furman, 2001). For example, vertigo and unsteadiness have been associated with a fear of falling, which in turn is predictive of subsequent falls (Li et al., 2003; Delbaere et al., 2004). Furthermore, dizziness is often accompanied by emotional distress, anxiety, and depression (Yardley, 2000). Patients who have comorbid dizziness and psychological symptoms are more likely to remain symptomatic and have more disabling symptoms (Tinetti et al., 2000; Staab, 2006). The etiology of the disturbance is unclear, as the link appears to be a complex, two-way interaction whereby patients with psychological symptoms commonly report vestibular symptoms (e.g., dizziness), and conversely, patients with vestibular dysfunction may report psychological symptoms, e.g., anxiety, agoraphobia, depression (Balaban and Jacob, 2001; Balaban and Thayer, 2001; Pollak et al., 2003; Godemann et al., 2004; Eckhardt-Henn et al., 2008). Negative reinforcement is one way in which the cycle can be perpetuated. For example, patients who are dizzy may avoid situations that make them feel dizzy. The anxiety they have about potentially feeling dizzy is reduced since they do not attend the situation. Therefore, in the future, they continue to avoid situations to not feel the anxiety. Moreover, fear and anxiety share overlapping neural circuitry and therefore there may be common neural mechanisms to both ARVL and anxiety (Balaban and Thayer, 2001). Overall, it is important to examine these associations in the elderly and in particularly in ARVL because the symptom course can be different in the young versus elderly population.

Health-related quality of life (HRQoL) measures how patients perceive their health and functional ability. HRQoL is a key health outcome measure and is indicated by the Centers for Disease Control as a central public health goal for the three Healthy People initiatives (Crosby et al., 2003; Palermo et al., 2008). Agrawal and colleagues 2018 found that patients with ARVL had poor health-related quality of life, even after controlling for other age-related variables such as hearing loss and vision loss, that are arguably more focused on by patients and providers. Assessing psychological factors as well as other patient-reported outcomes, such as Quality of Life, especially in ARVL is crucial for identifying and monitoring how patients are functioning. Despite the importance of assessing HRQoL, there is a scarcity of research and lack of appropriate measures in ARVL.

In summary, awareness of ARVL and associated psychological symptoms is important to ameliorate emotional impairments. Moreover, this information can be used to assist patients and caregivers in making informed decisions and managing risks. Of particular importance is attending to suicide risk as well as depression associated with impairments related to ARVL, such as falls. Furthermore, optimizing functioning of the vestibular system in the elderly can prevent social isolation, impairments in HRQoL, and psychological symptomology. Future research is needed in the area of mental health and ARVL to further examine these associations and create interventions to support patients. One potential avenue is integrating technology to assist with ARVL, such as rehabilitation techniques or to facilitate social engagement.

2. Discussion

This review addressed the myriad of impairments associated with age-related vestibular loss, specifically the associations between ARVL and vision, cognition, and psychological factors (see Fig. 1). Of particular interest are areas that have been understudied in age-related vestibular loss such as psychological functioning. Preliminary data has shown an association between age-related vestibular loss and fear, depression, and anxiety. Future research should investigate how ARVL impacts psychological well-being as well as consider potential pathways common to both vestibular and emotional networks. In addition, the ARVL contribution to specific cognitive abilities (e.g., executive aspects of spatial planning and organization) as well as the ARVL relationship to key components of frailty (the emergence of reduced gait speed) require closer attention. Collectively, the wide range of impairments discussed in this review indicates that ARVL is not evolving as a solitary process, but rather unfolding in the context of psychological, physical, and cognitive changes. Recognition of ARVL as part of a multi-faceted complex aging process will help guide the development of integrated interventions for patients who remain at risk for decline. Furthermore, validated patient-reported outcome measures are needed to evaluate interventions and monitor patient functioning. Future research should focus on considering broader patient-reported outcomes which is a priority of the National Institute of Health, the Food and Drug Administration, and the Center for Medicare and Medicaid services.

Given the interdependence of multiple areas of functioning, this highlights the importance of multidisciplinary care in providing health services to patients with age-related vestibular loss. Ensuring that all areas of functioning are screened for and assessed is crucial, particularly cognition and psychological functioning. Integrated multidisciplinary care will help address overlapping deficits and improve patient quality of life. Although this may be challenging due to some providers not frequently being involved in medical teams, such as psychologists and audiologists, telehealth has emerged as an option for providing these healthcare services. Via telehealth, a team-based virtual clinic model may be implemented which will allow multidisciplinary care and screening of mental health and cognition. Using a hybrid model that includes evaluation of vestibular functioning using the traditional in-clinic model, while conducting cognitive and emotional evaluations using a telehealth model may be a viable option to complete comprehensive evaluations of patients with age-related vestibular loss.

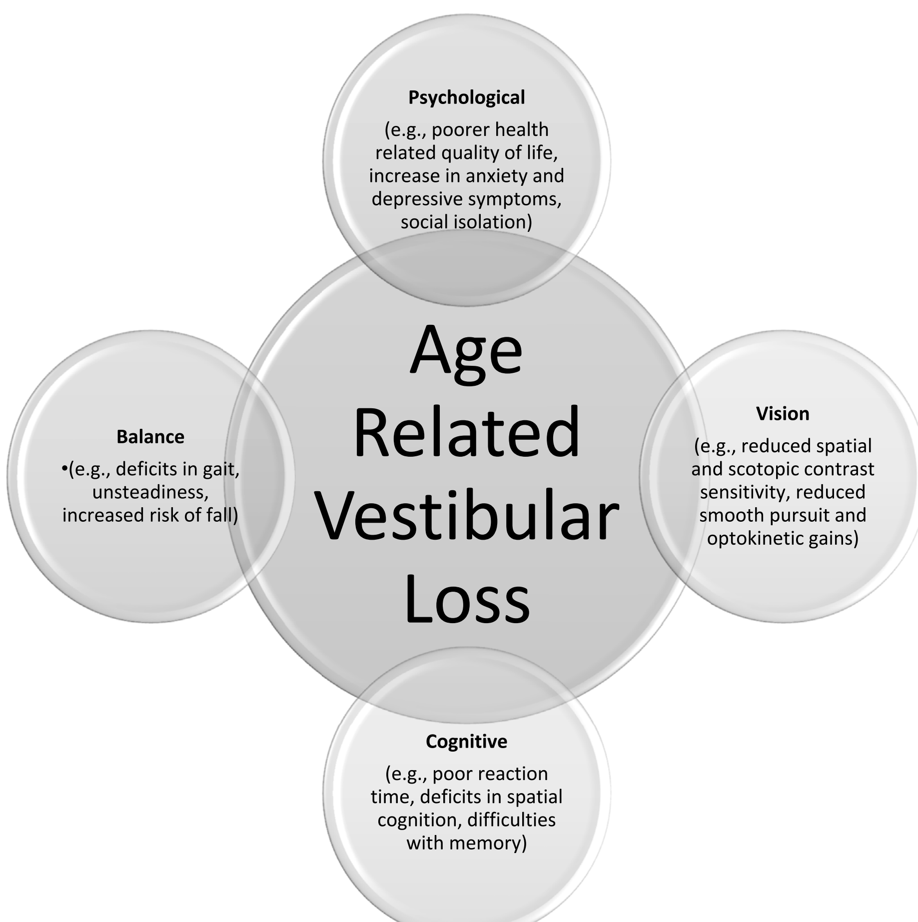

Fig. 1. Age-related vestibular loss and associated deficits.

Author contribution

All authors contributed to the conception, writing, and editing of the work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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