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Vestibular disorders and dual task performance: Impairment when walking a straight path

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Abstract

Locomotion is impaired in some people with vestibular disorders. Performance on cognitive tasks is also impaired in many people with vestibular disorders. The goal of this study was to determine if patients with vestibular disorders have decreased ability to complete a dual task performance involving a cognitive task, an additional motor task or both tasks, combined along a linear path. Subjects were normal, had benign paroxysmal positional vertigo, or had various vestibular disorders that caused unilateral weakness. They were asked to walk 7.62 m in a straight line with eyes open or closed, without extra tasks, and while nodding the head, naming things, and both nodding and naming. The patients walked significantly slower than controls, especially when performing the cognitive task. Patients had greater ataxia and began veering sooner than normals. The subjects' veering increased significantly with the addition of cognitive tasks. The patient groups did not differ significantly from each other. The changes in velocity did not affect the veering. These data suggest that patients with vestibular disorders are impaired in their ability to complete a linear path when cognitive tasks are added.

Keywords

Benign paroxysmal positional vertigo; unilateral weakness; cognitive performance; spatial orientation

1. Introduction

Humans use visual, somatosensory, vestibular, and auditory cues to complete locomotor tasks [1]. The vestibular end organs probably provide the inertial input to these tasks [2,3]. Visual, somatosensory and auditory cues are also available in providing input, but the vestibular system plays an essential role in establishing spatial coordinates. Beritoff first demonstrated this concept in his studies with deaf, mute, and anosmic children with and without vestibular function [4]. He showed that the children with vestibular function could return to a point identified along a route during passive transport but children with deficient vestibular function could not return.

Both linear and rotary signals from the vestibular system are used to compute location [3]. In particular, Israel and Berthoz verified the linear component of the computation [5]. They

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showed that during passive linear displacement, normal subjects could track a target in darkness and remember the trajectory and amount of head displacement. In contrast, four subjects without labyrinths could not stabilize their gaze. This linear information, at times in combination with rotary information from the semicircular canals, alone, can be used to update one's position when visual and somatosensory input is not available.

Several studies have examined the effect of vestibular disorders on active, linear locomotion. Glasauer et al showed that patients with bilateral labyrinthine deficiencies could complete a linear task similar to normals in terms of distance error in reaching the target [7]. However, the labyrinthine deficient patients demonstrated a larger lateral error and path curvature and a slower walking velocity. Another analysis, with the majority of study patients with bilateral deficiencies, including a triangular path showed the error in the path occurred with the rotations required to complete the triangular path and not with the linear walking [8]. Previous work in our laboratory, with mostly unilateral vestibular deficient patients, has shown that, firstly, patients with chronic vestibulopathies veer sooner and at a greater angle while taking more time on an active, linear, walking task when compared to normals [9]. Secondly, vestibular rehabilitation improves those patients' performances in terms of velocity and angle of veering on the same task [10]. The cause of these changes is not well understood, and these experiments show that the sensorimotor input cannot completely compensate for the vestibular dysfunction.

The decreased performance may be due to an increased cognitive load from inaccurate vestibular input. Spatial updating is not just an automatic process; it requires the "attention" of central processing resources. Many studies have analyzed passive displacement and subsequent path completion or postural sway in determining the cognitive load necessary to return to a starting point or maintain balance respectively. Decreasing postural stability decreases reaction time to cognitive tasks in patients with compensated and acute vestibular disorders when compared to normals, but those normals also show decreased performance [11–13]. Yardley further showed that healthy subjects' performance of arithmetic tasks was impaired when performing a concomitant, rotational orientation task, and the effect was doubled in those with vestibular disorders [14]. These studies differed, however, when assessing the effect of the cognitive task on posture. Redfern's subjects' sway increased, Yardley's cognitive task had no effect on the sway, and others have even shown a decrease in sway. For example, Riley et al. showed that subjects' postural sway decreased when they were challenged with increasingly difficult number memory tasks [15]. These differences may be due to the variation in difficulty of the cognitive tasks performed in each study or to the ability to "quarantine" obvious sensory mismatches so they do not draw on attentional demands [16]. In contrast to the postural studies, most studies that examine locomotion show some decrement when cognitive tasks are added. For example, patients with vestibular disorders have been shown to perform worse on a continuous monitoring orientation task by inaccurately judging their rotational displacement during a cognitive task [17].

Our present study determined the effect of dual task performance on an active, linear walking task in subjects with and without vestibular disorders. We not only challenged the subjects with an additional cognitive task, but we also added an additional motor task to simulate real life motor problems [i.e. driving in a car while talking on a cell phone and turning one's head to change lanes with (day) and without (night) visual cues]. We hypothesized that subjects with vestibular disorders would veer more and walk slower than normals, and this effect would be exacerbated by adding tasks due to the increased attentional demands required to interpret the abnormal vestibular information and perform an extra task. We also hypothesized that patients with benign paroxysmal positional vertigo (BPPV) would be less impaired than other patients with vestibular disorders. Patients with BPPV would not have active symptoms unless their heads moved in the plane of the

diseased semicircular canals because they would have relatively intact vestibular systems providing accurate input in other planes.

2. Materials and methods

2.1. Subjects

The sample included 45 people, in three groups: normal controls, BPPV, and various vestibular disorders (VVD). See Table 1. Normal control subjects were recruited from the staff and visitors in our laboratory. They were screened for vestibular disorders by history, observation of gait, Dix Hallpike maneuver, head shake and head thrust tests. They had no other otologic or orthopedic diagnoses.

The VVD group included 7 patients with stable unilateral Meniere's disease, one Meniere's patient who was three months post-unilateral labyrinthectomy, three patients with vestibular neuronitis (one seen one day after symptom onset), two patients post-unilateral acoustic neuroma resection (one 6 years post- middle cranial fossa craniotomy and one 7 years post translabyrinth resection), one patient with chronic vestibulopathy, and one patient with vestibular hydrops. No patients were acutely vertiginous during the trials and all (except for the acute presentation of the neuronitis) suffered chronically from their disease.

Patient subjects were recruited from among patients referred to our laboratory for objective vestibular diagnostic testing and from among patients being seen for follow-up to the neurotology clinic. Board certified otolaryngologists or neurologists made the diagnoses based on clinical impression and diagnostic tests including audiograms, MRI, and ENG. The diagnosis of BPPV was confirmed with the Dix Hallpike test. The two patient groups were also screened for other otologic, orthopedic, or any other disorders that would hinder their performance during the trials.

2.2. Task

Testing was performed in a 9.45 × 30.1 m room. Subjects were asked to walk at a normal pace, with the participant's normal gait, along a 7.62 m straight line. Subjects were told to stop once they reached the endpoint. This task has been described previously [8]. The four task conditions were performed six times using two visual conditions, 3 trials with eyes open (EO), and 3 trials with eyes closed (EC). In Condition 1 subjects walked in a straight line (walking). In Condition 2 they performed a naming task while walking, e.g. naming girls or boys names for each letter of the alphabet (walking/naming). In Condition 3 they pitched their heads up/ down while walking (nodding/walking). In Condition 4 they performed the naming and nodding tasks, simultaneously (naming/nodding/walking). For every subject all tests were given in a random order by the observer who was not blinded to the patient status.

Each trial was timed using a stopwatch. The veer onset (VO), i.e. the forward distance walked before veering, and the horizontal deviation were recorded, based on pre-measured markings on the floor. From those data the angle of veering (angle) and the velocity were calculated. See Fig. 1.

Prior to testing, all participants gave informed consent. This study was approved by the Institution Review Board for Baylor College of Medicine and Affiliated Hospitals.

2.3. Statistical methods

Each subject performed four tasks (walking in a straight line, talking while walking, head nodding while walking, talking and head nodding while walking) 6 times each: 3 times with eyes open, and 3 times with eyes closed. Within each eye condition (open and closed) the 3

scores were summed and averaged, and a final score for each task/eye condition was computed (i.e., walking score with eyes open, walking score with eyes closed, etc.).

Multilevel statistical methods [15] were used to describe changes in the dependent variables of interest (VO, velocity, angle of veering) during the tasks (walk, name/walk, nod/walk, name/nod/walk) and visual conditions (eyes open and eyes closed). The three study groups (healthy controls, BPPV, VVD) were compared using these parameters. A separate model was produced and fitted to each dependent variable. Within each model, we examined the significance of within subject effect (within subject over tasks and over eye conditions) and between subjects (between the 3 study groups). Interaction effects were included in each model and tested. Changes over tasks and eye conditions were compared among groups by using a likelihood ratio statistic which follows a chi-square distribution. Adjustments were made for multiple comparisons. $P < 0.05$ was considered as statistically significant. All analyses were performed using SAS Statistical software (SAS, Carry, NC).

3. Results

3.1. Veer onset

With eyes open, VO did not differ significantly among groups or conditions. With eyes closed, however, the controls differed significantly from the two vestibular groups ($p = 0.0004$ control vs. BPPV; $p < 0.0001$ control vs. various); the controls walked farther without veering. No difference was found between the two patient groups. Overall, no within group differences were found by task with eyes closed. Essentially, the degree of veer onset did not change from one task to another. (See Table 2, Fig. 2).

3.2. Velocity

The two patient groups walked significantly slower than the control group, with eyes open and with eyes closed (EO − $p = 0.02$ control vs. BPPV, $p = 0.002$ control vs. VVD; EC □ $p = 0.0008$ control vs. BPPV, $p < 0.0001$ control vs. VVD). The magnitude of the difference was greater when eyes were closed. The two patient groups did not differ significantly from each other with eyes open or closed. Also, in general, within each group (diseased or healthy controls), the two conditions that included a cognitive task (naming/walking and naming/nodding/walking) were performed significantly slower than tasks without the added cognitive challenge (walking or nodding/walking). (See Tables 3a and 3b, Fig. 3a and 3b.)

3.3. Angle of veering

With regard to the angle of veering, no group differences were seen with eyes open. Both patient groups performed as well as healthy controls. With eyes closed, the VVD group had a significantly greater angle of veering than controls during the two conditions with the cognitive task: walking/naming and naming/nodding/walking. Specifically, during naming/walking healthy controls did not have a significantly smaller angle of veering than the BPPV group [crude $p = 0.003$, adjusted $p = 0.1$ (trend, adjusted for multiple comparison)]. Healthy controls did have a smaller angle of veering than the VVD group (crude $p < 0.001$; adj. $p = 0.004$). Again, the difference approached significance with the naming/nodding/walking task (crude $p < 0.01$; adjusted $p = 0.1$). This finding suggests an influence of a cognitive task on angle of veering in the VVD group. The 3 groups performed similarly when walking or when nodding/walking. (See Table 4a, Fig. 4).

3.4. Eyes open vs. closed

Overall, all 3 groups veered earlier, walked slower, and had higher angle of veering with eyes closed than with eyes open ($p < 0.001$).

3.5. Velocity effect on veering

Angle was correlated with velocity only in the VVD group during the eyes closed conditions ($r = -0.6$, $p = 0.01$). In the remaining groups and conditions, as velocity increased, the angle of veering did not significantly decrease.

4. Discussion

The patient groups performed worse than the control group on the task when vision was not available to compensate for the deficient vestibular system. The patient groups walked slower and veered earlier. Angle of veering seemed to be affected by cognitive tasks, such as talking, in the VVD group, and approached significance in the BPPV group.

The VVD group was comprised of patients with chronic vestibular disorders. The majority of these patients did not take part in the study during their original presentation of acute symptoms. Due to the chronic nature of their vestibular disorders, most patients likely had some compensation for their vestibular deficiency. The performance of these patients was between the post-operative acoustic neuroma (AN) patients and the chronic vestibulopathy (CV) patients described in a previous study, in which both groups veered earlier than controls, the CV patients' angle was significantly greater and the acutely post-operative AN group veered more than controls [9]. The compensated post operative AN group did not veer more than controls, however. The less significant findings when analyzing angle in this study was likely due to the heterogonous diseases that composed the VVD group.

Both patient groups in the present experiment walked significantly slower, with eyes open or closed, or approached significance, especially when performing the cognitive task. Dual task performance was not tested in Cohen's initial study. The decrease in velocity reinforces the idea of competing attention demands, especially when a deficiency in the vestibular system is an exacerbating factor. During a passive orientation task in Yardley's experiment, healthy volunteers were less accurate in returning to a starting position with a competing cognitive task [18]. In her follow up study, the inaccuracy in judging orientation was increased in patients with vestibular imbalance and was correlated with the severity of the symptoms [14]. Our patients did not show as significant an inaccuracy in finding their way to the correct position, but they took longer to perform the task. Our patients were not tested on their responses to the cognitive task; therefore, they could easily prioritize the path integration task over the cognitive task. They were able to walk slower while performing the various tasks and achieve an accurate result.

Peruch et al. found that Meniere's patients performance was correlated with the complexity of an accompanying mental task [19]. Our cognitive task was not complex. This low complexity may have contributed to the ability to complete the task more accurately. The effect of the dual tasks may be on a continuum, with less complex tasks only affecting the velocity, while as the task becomes more complex the patients may begin to veer more.

This experiment added a motor component to the dual task performance. The addition of nodding, however, did not significantly affect the variables. Only one patient in this study was greater than 70 years old. In Harley's study on dual task performance with a cognitive and motor (stepping over an obstacle) tasks, she found that only the performance of healthy subjects aged 70–79 decreased with the addition of an obstacle when compared to subjects aged 20–29 and 60–69 [20]. Our patients, who had no additional orthopedic or neurologic diseases, could easily adjust to performing the simple task of nodding.

The BPPV group did not perform differently from the VVD group. All of the BPPV patients were tested during an acute presentation with active vertigo on Dix Hallpike maneuvers.

One may expect the BPPV patients to behave no differently than controls unless one of the movements during the task was in plane with the respective, diseased semicircular canal. Their consistent similarity may be due to the unloading of the utricle. In BPPV, otoconial matter becomes removed from the utricle to the posterior semicircular canal, probably changing the inertial properties of the otoconial membrane. These patients can have changes in standing balance most likely due to the change in the otolithspinal reflexes and probably have additional changes in their walking balance [21,22]. Since linear acceleration signals are important for path completion, the altered linear acceleration signal from the utricle may have decreased the ability of BPPV patients to perform this task [3].

The patient groups walked significantly slower than the controls. Using a similar task Dickstein et al found that when healthy individuals were blindfolded they departed less from a straight-ahead path while running [23], suggesting that speed of gait may play a role. Patients with acute vestibulopathies also veer less when performing path integration tasks at faster speeds. Brandt et al. observed four patients with vestibular neuritis performing a linear path integration task at varying speeds [24]. In contrast to these previous studies, velocity did not affect the performance of our subjects even though the patient groups walked significantly slower, probably because none of the subjects ran while performing the task. Their gait speeds varied slightly by individual but walking did not allow the variation in foot placement that Dickstein et al hypothesized would lead to improved performance while running.

In conclusion, the patients' performance on this linear path was affected by adding additional, simple tasks. Performing this task requires attentional demands, and the effect on adding tasks exacerbated the decreased performance by vestibular patients. Patients with vestibular disorders need counseling to perform daily tasks safely in this world of multitasking, especially at night, when there are less visual cues.

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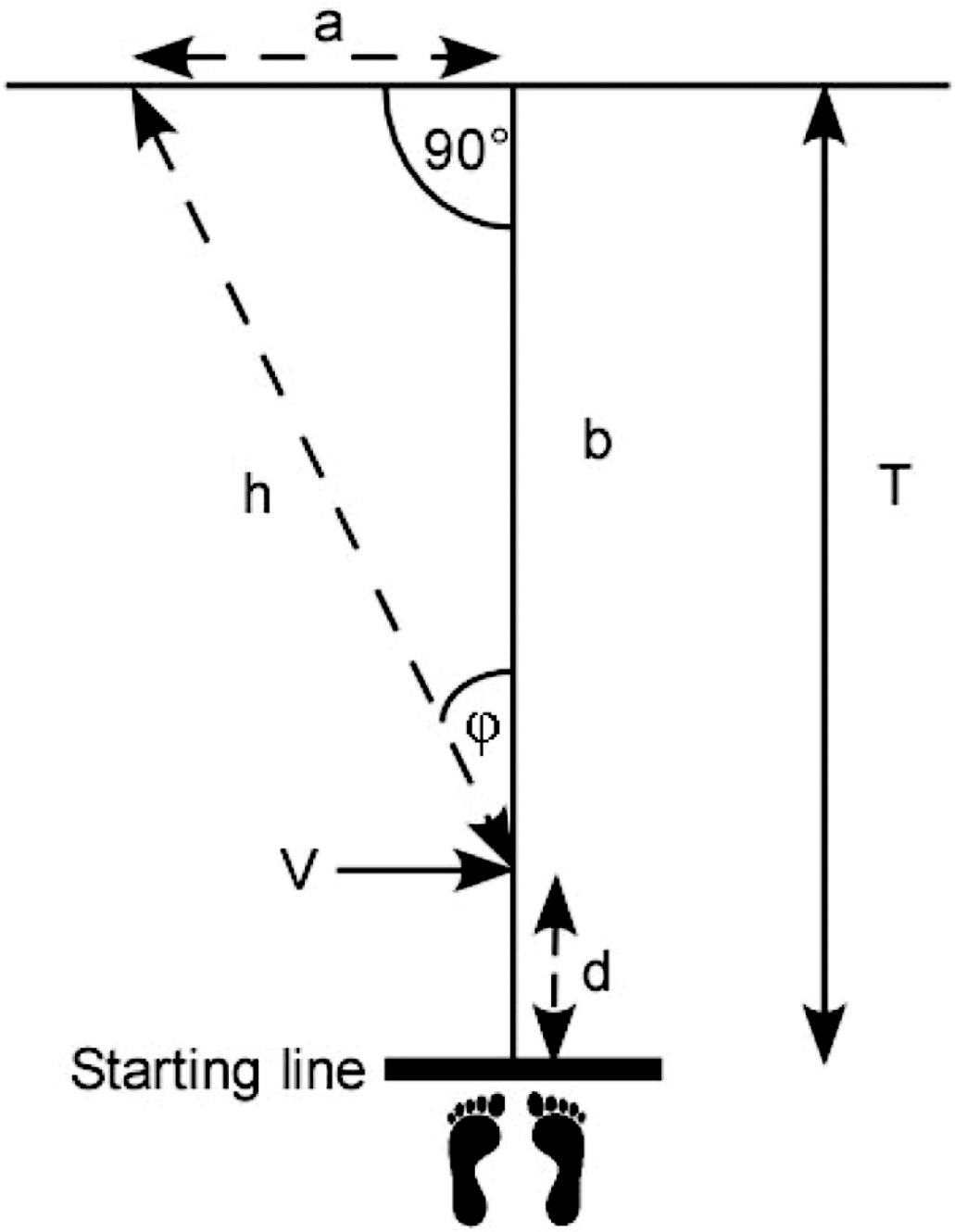

Fig. 1.

Diagram of the task for a subject who veered to the left. Subjects were instructed to start at the starting line and walk the distance, T. (Feet are not to scale.) Subjects who veered to either side walked some distance, d, to point V, at which they veered some angle, ϕ, continuing along the trajectory, h, to cross the finish line at point a, h, having moved laterally through some distance, a. For subjects who veered, the total distance walked was h + d. h = the square root of a2 + b2, when b = T – d and T = 7.62 m. Subjects who did not veer walked distance d + b, and d + b = T, or 7.62 m. (Reference 8. Used by permission of IOS press).

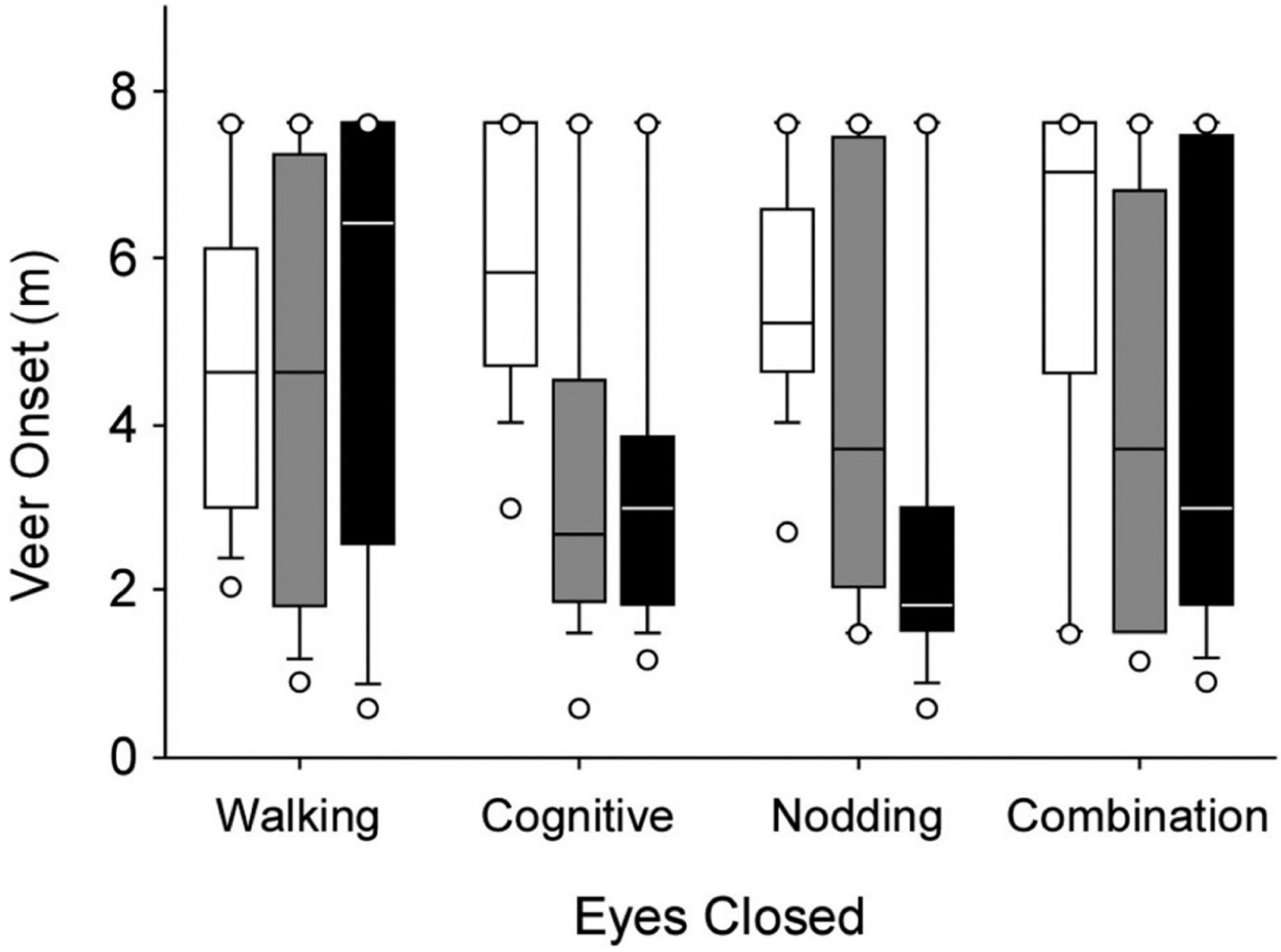

Fig. 2.

Change in veer onset with eyes closed over the four conditions for the 3 groups. The top and bottom of the box represent the 75th and 25th percentiles respectively, the middle line is the 50th percentile, the whiskers extending from the top and bottom of the box represent the 90th and 10th percentiles, with the circles as outlier caps. BPPV = benign paroxysmal positional vertigo, variable = various vestibular disorder group.

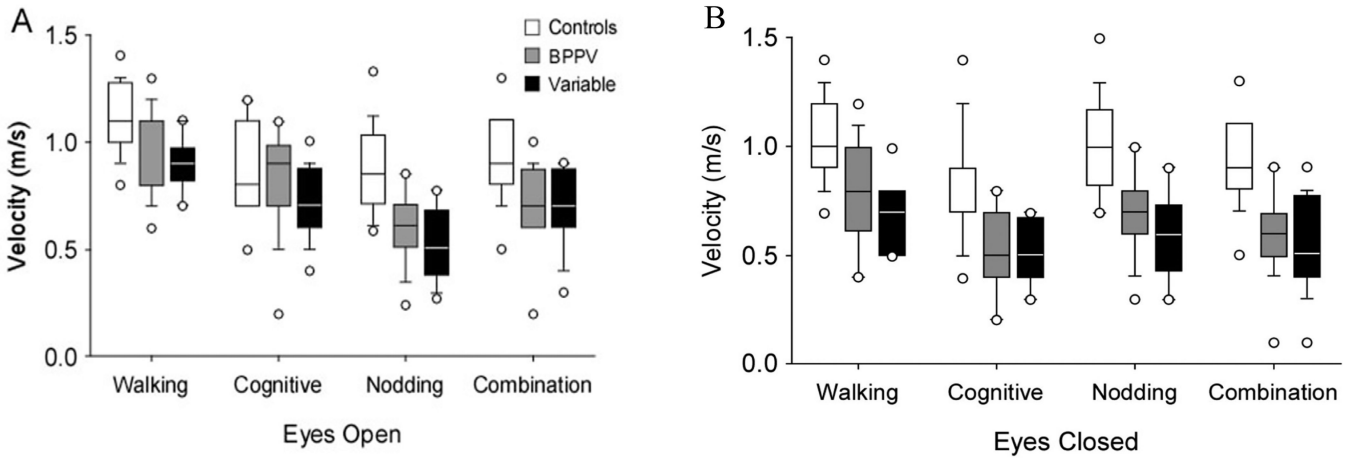

Fig. 3.

Change in velocity with eyes open (A) and eyes closed (B) over the four conditions for the 3 groups. The top and bottom of the box represent the 75th and 25th percentiles respectively, the middle line is the 50th percentile, the whiskers extending from the top and bottom of the box represent the 90th and 10th percentiles, with the circles as outlier caps. BPPV = benign paroxysmal positional vertigo, variable = various vestibular disorder group.

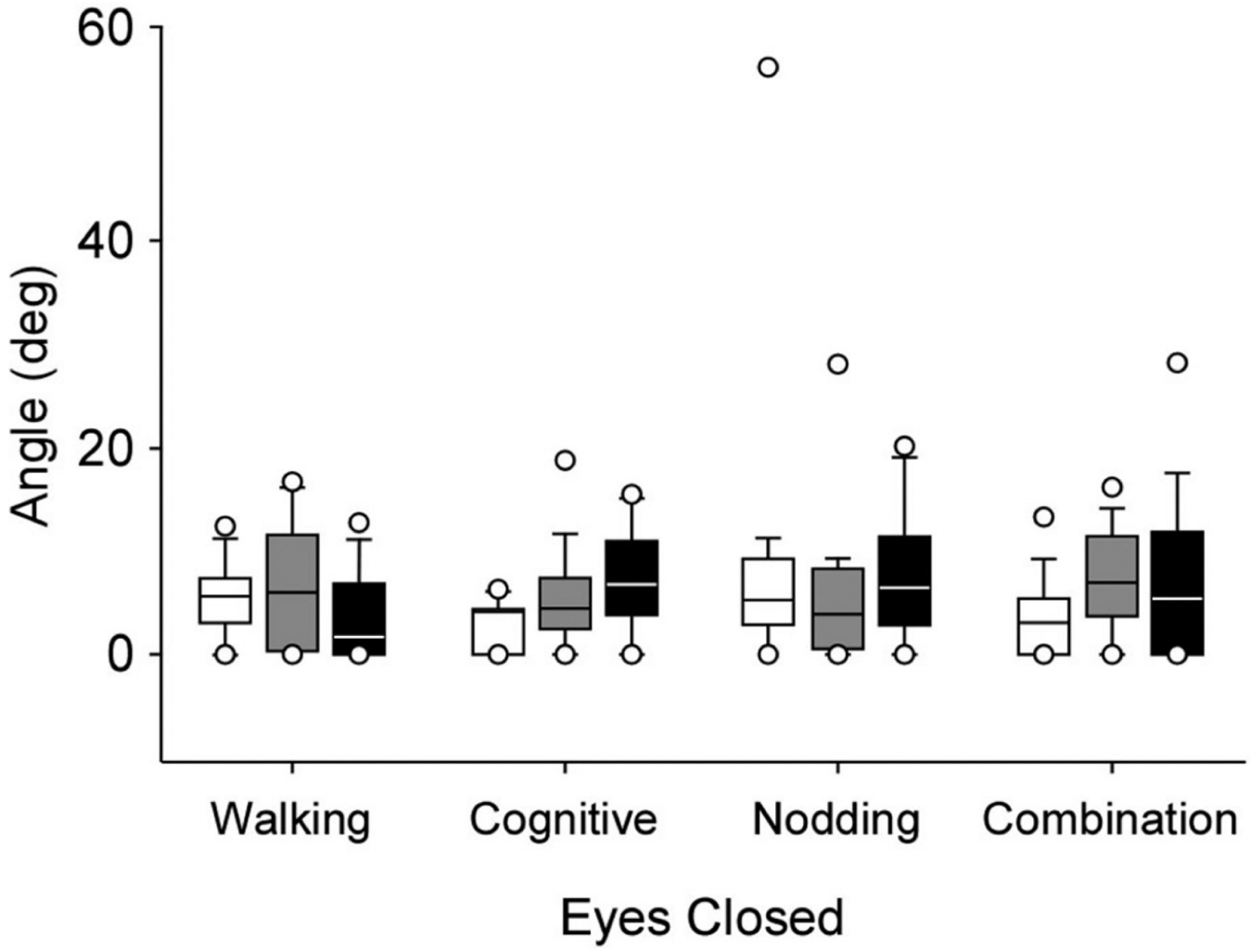

Fig. 4.

Change in angle with eyes closed over the four conditions for the 3 groups. The top and bottom of the box represent the 75th and 25th percentiles respectively, the middle line is the 50th percentile, the whiskers extending from the top and bottom of the box represent the 90th and 10th percentiles, with the circles as outlier caps. BPPV = benign paroxysmal positional vertigo, variable = various vestibular disorder group.

Table 1

Subject demographics. Age in range (mean ± standard error), BPPV = benign paroxysmal positional vertigo, Various = various vestibular disorder group

	Control	BPPV	Various disorders
N	15	15	15
Age	35.6–68.4 (48.5 ± 9.8)	36.6–72.5 (55.6 ± 9.8)	34.4–73.2 (51.6 ± 10.5)
Gender	7 Females 8 Males	10 Females 5 Males	9 Females 6 Males

Table 2

Veer onset in the Eyes Closed conditions. Mean values in meters (+ standard error) (BPPV – benign paroxysmal positional vertigo, Various – various vestibular disorder group)

	Walking	Naming	Nodding	Combination
Normals	5.1 + 0.4	6.2 + 0.4	5.5 + 0.4	6.0 + 0.4
BPPV	4.6 + 0.4	3.9 + 0.4	4.2 + 0.4	3.9 + 0.4
Various	4.4 + 0.4	3.9 + 0.4	3.6 + 0.4	4.1 + 0.4

Table 3

a Velocity in the Eyes Open condition Mean values in meters/second (+ standard error). (BPPV – benign paroxysmal positional vertigo, Various – various vestibular disorder group)

	Walking	Naming	Nodding	Combination
Normals	1.13 + 0.05	0.9 + 0.05	1.09 + 0.05	0.9 + 0.05
BPPV	1.03 + 0.05	0.73 + 0.05	0.88 + 0.05	0.68 + 0.05
Various	0.93 + 0.05	0.69 + 0.05	0.82 + 0.05	0.68 + 0.05

b Velocity in the Eyes Closed conditions. Mean values in meters/second (+ standard error). (BPPV – benign paroxysmal positional vertigo, Various – various vestibular disorder group)

	Walking	Naming	Nodding	Combination
Normals	1.08 + 0.05	0.79 + 0.05	1.02 + 0.05	0.81 + 0.05
BPPV	0.82 + 0.05	0.56 + 0.05	0.72 + 0.05	0.57 + 0.05
Various	0.7 + 0.05	0.56 + 0.05	0.65 + 0.05	0.54 + 0.05

Table 4

a Angle veered in the Eyes Open conditions. Mean values in degrees (+ standard error). (BPPV – benign paroxysmal positional vertigo, Various – various vestibular disorder group)

	Walking	Naming	Nodding	Combination
Normals	0.0	0.7 + 0.4	0.2 + 0.3	0.1 + 0.3
BPPV	0.0	0.3 + 0.4	0.4 + 0.3	0.2 + 0.3
Various	0.0	0.4 + 0.4	1.1 + 0.3	0.6 + 0.3

b Angle veered in the Eyes Closed conditions. Mean values in degrees (+ standard error). (BPPV – benign paroxysmal positional vertigo, Various – various vestibular disorder group)

	Walking	Naming	Nodding	Combination
Normals	4.4 + 0.7	2.8 + 0.8	6.1 + 1.1	2.5 + 0.8
BPPV	5.1 + 0.7	6.3 + 0.8	5.7 + 1.1	5.8 + 0.8
Various	5.3 + 0.7	7.7 + 0.8	6.2 + 1.1	5.7 + 0.8