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Computerized Dynamic Visual Acuity With Volitional Head Movement in Patients With Vestibular Dysfunction

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Objectives: Patients with uncompensated vestibular dysfunction frequently report blurred vision during head movement, a symptom termed oscillopsia. One way to measure the functional deficit associated with an impaired vestibulo-ocular reflex is by comparing visual acuity from a baseline condition in which there is no head movement to visual acuity obtained during a dynamic condition with head movement. A previously described test incorporated a treadmill upon which patients walked during assessment of visual acuity. The objective of the current investigation was to evaluate an alternative method of assessing dynamic visual acuity that uses volitional head movement instead of walking on a treadmill.

Methods: Fifteen participants with normal vestibular function and 16 participants with impaired vestibular function were enrolled. All participants performed the visual acuity task under baseline conditions with no movement and also under dynamic conditions that included 1) walking on a treadmill and 2) volitionally moving their head in the vertical plane.

Results: No difference in performance was observed between the treadmill task and the volitional head movement task. Participants with impaired vestibular function performed more poorly under the dynamic conditions than did participants with normal vestibular function.

Conclusions: The results suggest that the volitional head movement paradigm may be useful in identification of patients with functional deficits of the vestibulo-ocular reflex.

Key Words: bilateral vestibular dysfunction, dynamic visual acuity, oscillopsia, unilateral vestibular dysfunction, vestibulo-ocular reflex.

INTRODUCTION

A common complaint of patients with chronic uncompensated vestibular dysfunction is unstable gaze during active head movement.[1] The primary origin of this symptom is disruption of the vestibulo-ocular reflex (VOR).[2] The VOR is responsible for gaze stabilization when the head is in motion by initiating compensatory eye movements to decrease retinal slippage and maintain visual acuity.[3] In patients with vestibular system dysfunction, inaccurate vestibular information concerning the position of the head leads to slippage of the image from the retinal fovea. This causes blurred vision during head movement, a condition that has been termed oscillopsia.[4] For patients with a vestibular impairment who experience oscillopsia, the simple activity of reading signs while walking or driving may be difficult. These tasks create head movements for which the eyes must compensate to maintain gaze.

Several tests of dynamic visual acuity (DVA) have been reported as a means of assessing the impact of impaired vestibular function.[1,5-10] These tests are generally scored by comparing a DVA score, with head movement in the vertical and/or horizontal planes, to a baseline visual acuity score obtained with no head movement. Patients who have normal VOR function should have little degradation in visual acuity for these comparisons. Conversely, a patient with uncompensated VOR dysfunction would be expected to demonstrate degradation in visual acuity with head movement in comparison with a baseline score. It is noted that age has also been shown to have a negative influence on DVA.[8,10,11]

Bhansali et al[1] reported a simple method of measuring DVA with a Snellen eye chart in participants with bilateral vestibular dysfunction (BVD). Participants were instructed to volitionally move their heads in the horizontal plane at a frequency of 1 Hz while reading aloud letters on the eye chart. Abnormal DVA was observed in 18 of 22 participants

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(82%). Although an advantage of the method used in this study was that the only material needed was a Snellen chart, there is a potential disadvantage in that the limited number of letters may make memorization of the stimuli possible with repeated trials. This would preclude its use in serial measures or possibly even as a pretherapy and post-therapy measure. An additional limitation was the frequency of head movement used. At 1 Hz, the ability of the VOR to maintain gaze is influenced by other eye movement systems such as the pursuit system.[1,12] Also, typical head movements are associated with frequencies greater than 1 Hz.[1,2] Activities such as walking or running produce head movements at frequencies from 1 to 6 Hz, with harmonics present above this range.[2,13] A rate of at least 2.0 Hz should be used to measure DVA outside the influence of the pursuit system and at a rate that approximates natural head movements.

Herdman et al[8] used a computerized system to measure DVA in 3 participant groups: normal, unilateral vestibular dysfunction (UVD), and BVD. Participants indicated the direction of orientation of an optotype, "E," as it appeared on a monitor under baseline and dynamic conditions. For the dynamic condition, the participants volitionally moved their heads in the horizontal plane at a rate of 120°/s to 180°/s. Velocity of head movement was monitored with a rate sensor attached to the forehead of the participant. If head movement was outside the set range, the stimulus was not presented on the monitor. For the baseline conditions, there were no significant differences in the average of missed optotypes between groups. The dynamic condition of the test, however, was effective in differentiating normal participants from those participants with vestibular dysfunction, including differentiation of participants with UVD and BVD.

By using a rate sensor to monitor velocity of head movement, Herdman et al[8] were able to ensure that each participant was only tested at velocities outside the range of influence of other eye movement control systems. Longridge and Mallinson[5] provided velocity limits of smooth pursuit eye movement on the order of 50°/s to 100°/s, compared to an upper range of approximately 300°/s for VOR function. The initial investigation by Herdman et al[8] did not incorporate a vertical volitional head movement. Some have suggested that vertical head movement is important to assess because it is representative of everyday activities such as walking.[13] A subsequent study reported the efficacy of their task for vertical head movements.[11] The results indicated that the group with BVD did not perform as well as the group with normal vestibular function on their vertical DVA task. There was no difference in performance when the group with normal vestibular function was compared to groups with UVD or nonvestibular dizziness.

Although it is an important experimental control, a potential clinical limitation of their test is the use of a rate sensor. Incorporating a rate sensor will ensure that other eye movement systems are only contributing a slight influence, if any, on performance. The incorporation of such instrumentation, however, would certainly increase the cost of the test equipment. Given the lack of a reimbursable code for testing DVA, the expense of such equipment may preclude its widespread clinical use. Alternatively, if the clinician monitors and controls the amplitude of head rotation and the frequency of head movement, velocity will remain approximately constant.

Another test of DVA that incorporates vertical volitional head movement and a computerized system to test for oscillopsia has been described by Hillman et al.[9] Participants walked on a treadmill in place of actively moving their heads to assess DVA. This was used to create a more natural stimulation of the vestibular system. The study included 2 groups of participants: one with normal vestibular function, and a second with BVD. Participants read aloud 5 numbers randomly presented on a laptop computer monitor. On each trial, font size ranged from larger (20 points) to smaller (12 points). There was no apparent effort to ensure that all numbers at each font size were matched for difficulty of identification. Each patient performed the test while standing (baseline condition) and while walking (dynamic condition) on a treadmill. Results obtained with this paradigm were reported as reliable, with no difference in overall test-retest performance. There was a significant improvement in performance for the smallest font size on the second date of testing. The BVD group exhibited significantly poorer scores across all font sizes during walking, in contrast to the normal group, which only exhibited decreased performance for the 2 smallest sizes.

Although the use of a treadmill to produce realistic vertical head movements is reasonable, there are some potential disadvantages to treadmill use. Many clinicians do not have the physical space to add this equipment to their facilities, and the additional cost may also be prohibitive. Importantly, although all of their normal controls were able to walk at the set 6.4 km/h speed, only 1 of the participants with vestibular impairment was able to do this. Further, walking on a treadmill at the required speed may be medically contraindicated for certain patients with cardiovascular, orthopedic, and/or neuromuscular disease.

TABLE 1. PARTICIPANT CHARACTERISTICS

Participant Number	Age (y)	Sex	Disorder	Velocity mph	Velocity km/h
Normal vestibular function (n = 15)					
1	40	M	None	3.5	5.6
7	54	F	None	3.5	5.6
8	46	F	None	3.5	5.6
11	66	M	None	3.0	4.8
13	51	M	None	3.0	4.8
14	58	M	None	2.5	4.0
17	66	F	None	3.5	5.6
18	27	M	None	3.5	5.6
21	47	M	None	3.5	5.6
22	69	M	None	3.5	5.6
24	41	F	None	2.5	4.0
25	56	F	None	3.0	4.8
26	35	M	None	3.5	5.6
28	27	F	None	3.5	5.6
29	44	M	None	3.0	4.8
Mean	48				
Impaired vestibular function (n = 16)					
2	52	F	BVD	3.5	5.6
3	59	M	BVD	3.5	5.6
4	52	M	BVD	3.5	5.6
5	66	F	UVD	3.5	5.6
6	49	F	UVD	3.5	5.6
9	66	F	HFV	3.0	4.8
10	57	M	UVD	3.5	5.6
12	61	F	UVD	2.0	3.2
15	69	F	UVD	3.0	4.8
16	67	F	UVD	2.0	3.2
19	46	F	UVD	3.5	5.6
20	67	F	UVD	1.5	2.4
23	59	F	UVD	2.8	4.5
27	62	F	UVD	2.5	4.0
30	45	F	HFV	2.5	4.0
31	54	F	HFV	3.0	4.8
Mean	58				

BVD — bilateral vestibular dysfunction; UVD — unilateral vestibular dysfunction; HFV — high-frequency vestibulopathy.

The participants in this study were screened for such conditions, but screening may not be feasible in many clinics. Because many of the patients at dizziness and balance centers may have at least some of these problems, alternatives to the use of a treadmill for dynamic movements should be examined.

The purpose of the current investigation was to evaluate a test of DVA that incorporates aspects of the procedure described by Hillman et al.[9] The main difference is that the current test uses volitional head movement in the vertical plane in place of a heelstrike-induced vertical head movement elicited by walking on a treadmill. In all other regards, the methods of the studies are similar.

The overall goal of this investigation was to determine whether similar results could be obtained for a volitional head movement task in the vertical plane as for the treadmill task used by Hillman et al.[9] We were also interested in determining whether participants with impaired vestibular function (IV) performed differently than controls with normal vestibular function (NV). On the basis of the findings of Hillman et al[9] and others,[1,8,14] it was hypothesized that both groups would perform similarly for the baseline condition, but that the IV group would perform more poorly for the dynamic conditions.

MATERIALS AND METHODS

Participants. All participants were recruited from patients seen at our facility. The participants were provided with and signed an informed consent document. The participants in this study were 31 adults enrolled sequentially and selected into 1 of 2 groups based on vestibular function. Fifteen participants were assigned to the NV group, and 16 participants were assigned to the IV group. Specific participant information is provided in Table 1.

Before evaluation, each participant completed a questionnaire to document relevant case history information. This included documentation of normal cardiac, pulmonary, respiratory, and musculoskeletal function in order to ensure the safety of the participant during the treadmill portion of the experiment. All participants received a comprehensive vestibular function evaluation. Participants assigned to the IV group were all referred to our facility because of the presence of subjective symptoms consistent with uncompensated vestibulopathy (ie, dizziness with head or body movement, dysequilibirum, oscillopsia, etc). None had participated in any vestibular rehabilitation therapy before their participation in the current study. All patients underwent appropriate otolaryngological and neurologic evaluation. Unilateral vestibular dysfunction was defined as at least a 25% difference (unilateral caloric weakness) between the ears. Bilateral vestibular dysfunction was defined as a total bithermal caloric response (slow-phase eye velocity) of less than 22°/s, with no difference in response between the ears.[15] Participants with a clear vestibular event in their history, subjective report of oscillopsia, and normal caloric findings, but with a degraded vestibular autorotation test result, were identified as having high-frequency vestibulopathy (HFV).

Stimuli and Instrumentation. A laptop computer was used to present the Computerized Dynamic Visual Acuity Test (CDVAT). The computer monitor was placed 2 m from the patient. A Microsoft PowerPoint program was used to present the stimuli, which were similar to those used by Hillman et al.[9] The stimuli consisted of a string of 5 white numbers presented on a black background. Each of the 5 numbers was from the set 0, 1, 2, 3, 4, 5, 6, 7, 8, or 9. The 5-item number set was varied on each trial. The font was Tahoma, and the font size varied from 12 to 20 points in increments of 2 points. Previous data collected at our facility indicated no difference between numbers in identification of these number stimuli. Also, pilot data collected previously for 9 participants (mean age, 42 years; range, 26 to 68 years) on 2 separate occasions revealed intraclass correlation coefficients of r = 1.0 for the baseline condition and r = 0.98 for the dynamic volitional head movement condition, suggesting that this test is a stable measure with good intertest reliability for the volitional head movement task. As provided in Table 3 of Hillman et al,[9] these font sizes were selected for their study because when they are viewed at 2 m (as in the study of Hillman et al[9] and the current study), the stimuli correspond to a range of visual acuity from approximately 20/16 to 20/27 on a Snellen eye chart. In other words, a font size of 16 points viewed at 2 m approximates a Snellen ratio of 20/20.4.[9]

A 2.0-Hz auditory cue was presented with a Matrix (Seoul, Korea) MR500 quartz metronome during the volitional head movement condition. The treadmill condition was performed on a Landice (Randolph, New Jersey) model 8700 treadmill. The volitional head movement condition and the treadmill walking condition were performed in separate rooms. The rooms had similar lighting, so the contrasts of the computer screen were similar for each condition.

Test Protocol. The visual acuity of all participants was tested under 2 conditions (baseline and dynamic) and for 2 tasks (treadmill and volitional head movement). Baseline visual acuity was measured while the participant stood stationary on the treadmill and was also measured while the participant was seated with no head movement. Dynamic visual acuity was tested while the participant was walking on a treadmill at a velocity of 3.5 mph (5.6 km/h), which is slightly slower than the 6.4 km/h used in the Hillman et al[9] study. A slower treadmill velocity was used in the current investigation, because many participants in the Hillman et al[9] study could not perform the task at 6.4 km/h. Although the majority of the participants in each group were able to walk on the treadmill at this velocity, this rate had to be decreased for participants in both groups. Table 1 shows the actual velocity used for each participant. This treadmill velocity should produce head movement frequencies in the 1.0- to 2.0-Hz range.[16] The participants were not allowed to hold onto treadmill rails during data collection; the treadmill speed was adjusted to each participant's level of comfort up to a target velocity of 3.5 mph (5.6 km/h). A gait belt was used with all participants to ensure safety in case of loss of balance on the treadmill.

Dynamic visual acuity was measured while the participant was seated during the volitional vertical head movement task. Head movement was maintained at a constant rate of 2.0 Hz by having the participant move his or her head in time to an auditory cue. The head of the patient was oscillated at this frequency through about 40° of arc from up to down and returning to the upward position. This configuration produced a peak velocity of approximately 160°/s, which is above the range of pursuit eye movement. In some cases, the examiner would manually cue the participant's head to assist in maintaining the appropriate frequency and amplitude. Such cuing is not reported to affect results for participants who have difficulty with volitional head movement at higher frequencies.[17] Conditions and tasks were randomized to control for any potential order effects. Performance on each dynamic condition was compared to performance on the corresponding baseline condition.

For each condition and task, the participant was asked to verbally report each of the 5 stimuli observed on a trial. The participants had 3 seconds to report the stimuli before a new trial with different stimuli appeared. The font size varied randomly on each trial, and each font size was presented on 2 trials. There were 2 conditions (baseline and dynamic) for each of the 2 tasks (treadmill and volitional head movement) and 10 trials per condition and task; thus, 40 total trials were presented to each participant. The average testing time per patient was approximately 3 minutes per task and condition (12 minutes total). The examiner recorded the items reported on each trial and determined the percent correct for each font size for each task and condition. An overall measure of percent correct was also obtained by weighting each correct trial item at 2% (50 total items).

RESULTS

Data from both groups were averaged and plotted to examine trends. The results for the NV group are shown in Fig 1. The overall percent correct visual acuity for this group for the baseline seated task ranged from 100% to 92% (average, 98.4%), compared to 100% to 82.7% (average, 95.7%) for the dynamic volitional head movement task. Visual acuity for the baseline treadmill task ranged from 100% to

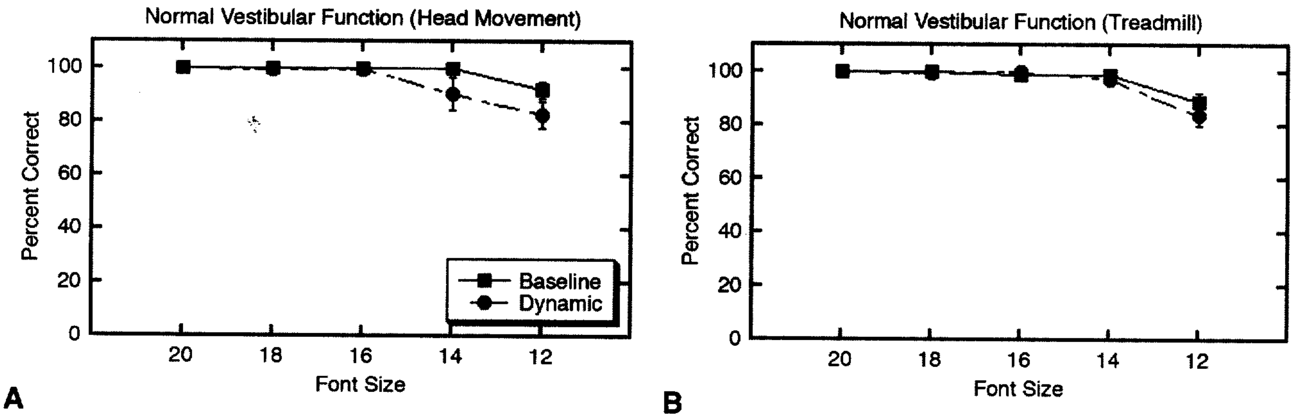

Fig 1. A) Average visual acuity performance of 15 participants with normal vestibular function for conditions without movement (Baseline) and with volitional head movement (Dynamic) is shown as function of font size. **B)** Performance for same participants without movement (Baseline) and walking on treadmill (Dynamic) is shown as function of font size. Standard error bars are provided.

88.7% (average, 97.2%), compared to 100% to 84% (average, 96.0%) for the dynamic treadmill task.

The results for the IV group are shown in Fig 2. The overall percent correct visual acuity for this group for the baseline seated task ranged from 100% to 91.3% (average, 97.9%), compared to a range from 88.1% to 36.3% (average, 69.0%) for the dynamic volitional head movement task. Visual acuity for the baseline treadmill task also ranged from 100% to 91.3% (average, 97.5%), compared to a range of 97.5% to 28.1% (average, 74.5%) for the dynamic treadmill task.

An analysis of variance (ANOVA) was used to examine the effects of group (normal or impaired), as well as condition (baseline or dynamic), task (treadmill or volitional head movement), and font size (12, 14, 16, 18, or 20 points), on visual acuity. The effect of group was significant [$F(1,29) = 13.43$; $p < .001$], as were the effects of condition [$F(1,29) = 27.33$; $p < .001$] and font size [$F(4,116) = 25.44$; $p < .001$]. A separate analysis excluding the data of the BVD subgroup yielded the same significant effects. The effect of task did not reach statistical significance [$F(1,29) = 2.20$; $p = .15$]. Three interactions were significant: group × condition [$F(1,29) = 17.35$; $p < .001$], condition × font size [$F(29,116) = 13.88$; $p < .001$], and group × condition × font size [$F(4,116) = 4.69$; $p = .001$]. These results indicate that the groups performed similarly for the baseline conditions, but that performance varied for the dynamic conditions; the IV group performed worse than the NV group on both tasks under the dynamic condition. The groups performed similarly for the larger font sizes, but diverged at smaller font sizes for the baseline conditions.

To further investigate the interactions, we analyzed the data of each group separately using an ANOVA to determine the effects of condition and font size. Data were collapsed on the factor task, as there was no effect in the previous analysis. For the NV group, the effects of both condition [$F(1,13) = 9.90$; $p < .001$] and font size [$F(4,56) = 7.36$; $p <$

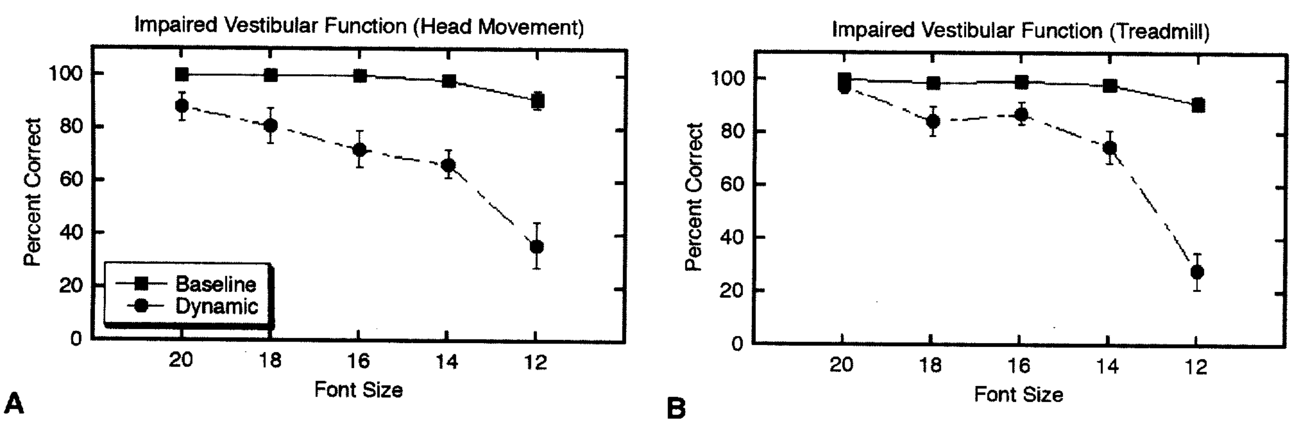

Fig 2. A) Average visual acuity performance of 16 participants with impaired vestibular function for conditions without movement (Baseline) and with volitional head movement (Dynamic) is shown as function of font size. **B)** Performance for same participants without movement (Baseline) and walking on treadmill (Dynamic) is shown as function of font size. Standard error bars are provided.

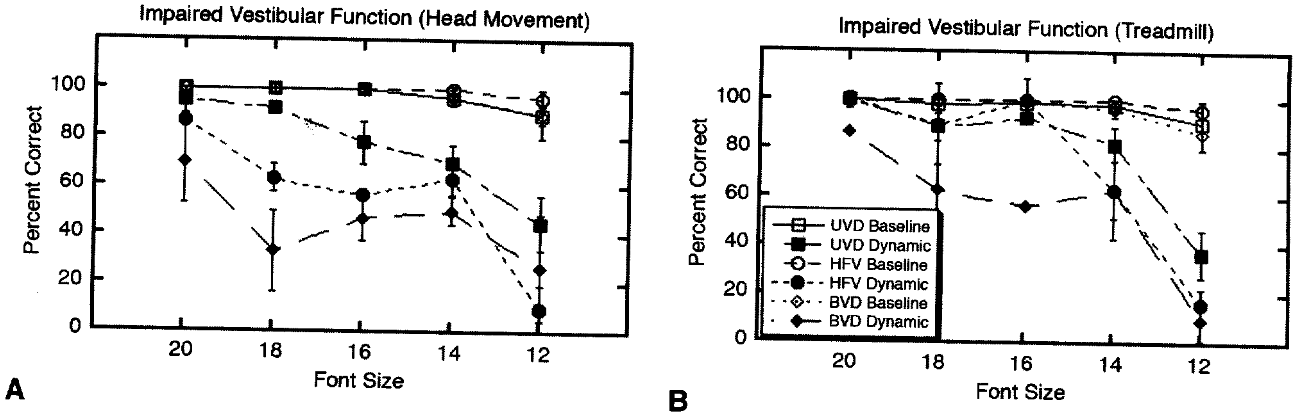

Fig 3. A) Average visual acuity performance of subgroups with impaired vestibular function for conditions without movement (Baseline) and with volitional head movement (Dynamic) is shown as function of font size. **B)** Performance for same subgroups without movement (Baseline) and walking on treadmill (Dynamic) is shown as function of font size. Standard error bars are provided. UVD — unilateral vestibular dysfunction; HFV — high-frequency vestibulopathy; BVD — bilateral vestibular dysfunction.

.001] were significant. There was no interaction. The NV group performed more poorly in the dynamic condition than in the baseline condition. Tukey's honest significant difference (HSD) post hoc analysis revealed that performance at a font size of 12 points was significantly poorer ($p < .01$) than for any other font size. There were no differences among any other font sizes.

For the IV group, the effects of both condition [$F(1,14) = 38.87$; $p < .001$] and font size [$F(4,60) = 43.60$; $p < .001$] were also significant. Unlike in the NV group, there was an interaction between condition and font size [$F(4,60) = 40.48$; $p < .001$]. The IV group performed more poorly in the dynamic condition than in the baseline condition. Tukey's HSD post hoc analysis revealed that performance with the 12-point font was significantly poorer ($p < .01$) than that with any other font size and that there were no differences among any other font sizes for the baseline condition. For the dynamic condition, Tukey's HSD post hoc analysis revealed that performance with the 12-point font was also poorer than that with any other font size. In addition, performance with the 14-point font was poorer than performance with the 20-point font. No other differences were observed.

The effects of vestibular impairment on DVA were also considered. Results for the subgroups UVD, BVD, and HFV are shown in Fig 3. The BVD subgroup exhibited degradation in visual acuity to a greater extent for the dynamic condition across all font sizes. This is followed by the degradation of the HFV subgroup, which also demonstrated decreased performance at most font sizes, but not to the extent of the BVD subgroup. Finally, the UVD group showed little degradation in DVA at the larger font sizes and showed greatest degradation at the smallest font sizes. For all font sizes, baseline performance was comparable for the groups, in agreement with the previous statistical analysis.

Overall percent-correct data are shown for the subgroups and the normal group in Table 2. For the 10 participants with UVD, the average degradation in visual acuity when baseline and dynamic conditions were compared was 22% (SE, 5.75%) for the volitional head movement task and 17% (SE, 3.86%) for the treadmill task. The 3 participants in the HFV subgroup performed similarly to, although slightly more poorly than, the UVD subgroup. An average degradation of 28% (SE, 9.24%) was observed for the HFV group for the volitional head movement condition, and an average degradation of 22.7% (SE, 6.77%) was observed for the tread-

TABLE 2. PERFORMANCE OF GROUPS OF PARTICIPANTS WITH VESTIBULAR DYSFUNCTION

Group	*n*	*Static Seated*	*Dynamic Volitional*	*Static Treadmill*	*Dynamic Treadmill*
Normal					
Mean	15	98.4	95.7	97.2	96.1
SD		2.5	9.5	4.3	4.4
95% CI		97.1-99.7	90.9-100.0	95.0-99.4	93.9-98.3
UVD					
Mean	10	98.2	76.0	97.2	80.2
SD		3.3	21.8	4.7	15.4
95% CI		96.2-100.0	62.5-89.5	94.3-100.0	70.6-89.8
BVD					
Mean	3	97.3	45.3	99.3	56.0
SD		4.6	24.4	1.2	16.1
95% CI		92.1-100.0	17.7-72.9	97.9-100.0	37.8-74.2
HFV					
Mean	3	97.3	69.3	96.7	74.0
SD		4.6	23.0	3.5	13.5
95% CI		92.1-100.0	43.2-95.4	92.7-100.0	58.7-89.3

CI — confidence interval.

mill condition. The 3 participants with BVD exhibited the largest degradation in visual acuity, with a much larger 52% degradation (SE, 13.01%) for the volitional head movement task and a 43.3% degradation (SE, 5.21%) for the treadmill task. Because there were only 3 participants in the BVD and HFV groups, statistical analyses were not performed on these data.

DISCUSSION

Effect of Task. The statistical analysis indicated no effect of task. Further, there were no significant interactions with task. This finding indicates that there is no difference in results obtained with the previously reported treadmill task and those obtained with a task incorporating volitional head movement. This is important, because many clinicians do not have the space or funding to incorporate a treadmill into a test of DVA. More importantly, many of the participants were unable to walk on the treadmill at the desired speed, and such an activity may be contraindicated for patients with certain health conditions. In the current study, 6 of the participants in the NV group and 9 of the participants in the IV group could not perform this task at the target treadmill velocity of 3.5 mph (5.6 km/h). This finding compares with that in the study of Hillman et al,[9] in which only 1 of the 5 participants with BVD was able to walk at the required treadmill velocity. It is also mentionable that none of the participants reported neck pain during or after the volitional head movement task.

Interaction of Condition, Group, and Font Size. Both the NV group and the IV group exhibited poorer performance for the dynamic conditions than for the baseline conditions. In fact, performance for the baseline conditions was comparable for the 2 groups. For the IV group, there was a greater difference in visual acuity between baseline and dynamic conditions than for the NV group, which demonstrated a smaller but significant difference. This finding is in agreement with that of Hillman et al.[9] Averaged across font size and collapsed on task, the degradation in visual acuity for the NV group was 1.9%. The degradation for the IV group averaged 31%. Direct comparison to other investigations of DVA in groups with normal vestibular function and impaired vestibular function is difficult because of methodological differences. Nevertheless, most reports indicate that participants with normal vestibular function perform better than those with impaired vestibular function.[1,8,14] The study by Dannenbaum et al[18] also indicates that patients with UVD experience greater difficulty with vertical DVA than do participants with an intact VOR. In their study, DVA was tested at 0.5, 1.0, and 1.5 Hz. They did not test it at 2.0 Hz because they had difficulty maintaining accurate head movements during the vertical motions. We did not observe this difficulty with our participants. Also, by using 2.0 Hz, we ensured that the participants' head movements were in a range reported to be consistent with typical head movements.[1,2,13] Further, this frequency is beyond the range of eye movement systems such as pursuit.[1,12]

Degradation in visual acuity was especially evident for the smaller font sizes, accounting for the interaction with this variable. A 12-point font size viewed from 2 m is equivalent to a Snellen ratio of 20/16.[9] Both groups had significantly poorer performance with this font size. However, only the IV group had significantly poorer performance with 14-point font than with 20-point font. This finding reflects the overall greater effect of head movement on visual acuity for this group, as would be expected, given the presence of impaired vestibular function. This difference is easily observed by comparing Figs 1 and 2. These findings agree with those of Hillman et al,[9] who also report more degradation for the 12-point font. An apparent difference is that Hillman et al[9] report significant degradation at all font sizes during walking on the treadmill for their group with impaired vestibular function. Their participants in this group all had BVD, which should lead to greater degradation in DVA. Most of the participants in our IV group had UVD. Comparison among subgroups is discussed in the next section.

Another issue that should be mentioned is the fact that the groups in the current investigation were not age-matched. At least 3 studies have shown that DVA is affected by age to some extent.[8,10,11] Herdman et al[8] found that DVA worsened with increase in age for their normal group; 42% of the variance of scores was accounted for by the age of their participants. On the other hand, only 24% of the variance of scores was accounted for by age in their group with BVD, and there was not a significant contribution of age to the variance in their group with UVD, although a trend in this direction was reported. In a separate study by Herdman et al,[10] 40% of the variability in DVA scores is again reported to be associated with participant age for their normal group. The data for the groups with impaired vestibular function are in conflict with the previous report,[8] however, as there was no relationship between age and performance for the BVD group. It was reported that 28% to 54% of the variability in DVA scores was attributable to age for their group with UVD,[10] while there was only a trend in the prior study.[8] Finally, in the report of Schubert et al,[11] 40% of the variance in scores was attributed to age for the normal group when only participants age 46 years or older were included. For their impaired group, 19% of the variance in scores was attributable to age for participants 46 years or older. Even with the slight discrepancies among studies, it seems clear that age has some effect on DVA. Nevertheless, we are in agreement with Herdman et al,[8,10] who report that impaired VOR has a greater impact on DVA than age.

Subgroups of Impaired Vestibular Function. Among the subgroups with impaired vestibular function, the UVD group showed the least degradation. In fact, 4 participants in the UVD group had normal DVA. In 2 it was normal for both tasks, in 1 it was normal for the head movement task only, and in 1 it was normal for the treadmill task only. All participants in the HFV and BVD groups had abnormal DVA. The HFV group had a decrement in DVA that was similar to, but slightly larger than, that of the UVD group.

The BVD group had the largest decrement in visual acuity. This finding was not surprising, as it is both intuitive and consistent with another study of DVA that specifically examined the difference in DVA performance between BVD and UVD participants.[8] This finding was also observed in a study of vertical DVA.[11] The authors reported that many participants in the group with BVD performed twice as poorly as the normal controls or their group with UVD. Schubert et al[11] also reported that their group with bilateral impairment performed significantly more poorly than other groups with normal vestibular function, nonvestibular disease, or unilateral vestibular impairment. Interestingly, 46% of the participants in this group exhibited normal vertical DVA. This finding was not observed in the current study, as all participants in our BVD group had abnormal visual acuity. Schubert et al[11] hypothesized that the bilaterally impaired participants who performed in the normal range on their task may have relied on eye movement systems other than VOR to maintain visual acuity. Another explanation offered was the possibility that these participants actually had some residual vertical semicircular canal function. This is not assessed with rotary chair and caloric testing, which were used to determine labyrinthine function and subsequent participant grouping by Schubert et al[11] but that stimulate primarily the horizontal canals. It is certainly possible that all of the participants with BVD in the current investigation truly had no labyrinthine function and performed more poorly on the DVA task.

Although the numbers of participants with BVD and HFV were limited in this investigation, the data in Fig 3 and Table 2 suggest that it may be possible to realize some differentiation among groups with impaired vestibular function. The BVD group had greater than twice the degradation in DVA that the UVD group exhibited. The HFV group also performed more poorly than the UVD group. Future investigations with larger numbers of participants is needed to determine whether clear differentiation is possible based on DVA performance. Nevertheless, given the results of the current investigation and other DVA studies, it would certainly be expected that participants with BVD would perform more poorly than those with UVD.

CONCLUSIONS

Dynamic visual acuity testing provides an excellent measure of the functional impact of VOR impairment. The current study compared performance on a previously used treadmill task to performance during volitional head movement in the vertical plane for participants with and without impaired vestibular function. The results indicate that 1) there was no difference in performance between the treadmill task and the volitional head movement task; 2) all participants exhibited greater difficulty with tasks of DVA than with baseline tasks with no movement; 3) participants with impaired vestibular function performed more poorly on the dynamic conditions than did participants with normal vestibular function, although all participants exhibited greater difficulty for the smallest font size used (12-point); and 4) it may be possible to differentiate participants with UVD from participants with BVD on the basis of DVA performance.

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