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Dynamic visual acuity following high-frequency head vibration

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DYNAMIC VISUAL ACUITY FOLLOWING
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by

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Abstract: In order to evaluate high-frequency VOR function, the effects of different types of motion on visual acuity were evaluated in asymptomatic and symptomatic subjects. A new testing protocol of evaluating vestibular function was developed in an effort to enhance current treatment protocols.

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INTRODUCTION AND REVIEW OF THE LITERATURE

Dizziness and imbalance are highly prevalent among the general population, ranging from 1.8% in young adults to more than 30% in the elderly (Sloan, Coeytaux, Beck, & Dallara, 2001). The common symptoms associated with dizziness and imbalance, such as headache, blurred vision and impaired mobility, substantially degrade quality of life and it is not surprising that patients seek treatment for these symptoms more and more frequently. The clinical diagnosis and management of patients with these symptoms is often difficult because dizziness can have multiple origins, including otologic dysfunction, cardiovascular and cardiac insufficiencies, neurological deficits, as well as idiopathic origins (Hain, 2006). Thus, in order to successfully manage a symptomatic patient, a thorough medical evaluation of the various symptoms is essential. This paper focuses on the vestibular origin of dizziness and a newly-developed testing protocol that evaluates a specific portion of the vestibular system called the vestibulo-ocular reflex (VOR).

In order to understand the vestibulo-ocular reflex, it is important to first look at the systems responsible for providing balance. To maintain balance, the human brain must receive and process input from three separate systems: the visual, vestibular, and somatosensory systems. When one of these three systems is impaired, a person may experience dizziness or imbalance.

The vestibular system is located in the inner ear and is comprised of three semicircular canals (SCC) and two otolithic organs that work together to help one maintain balance. The three SCC, known as the lateral/horizontal, posterior, and superior canals, are arranged perpendicularly to one another and provide information regarding motion and angular acceleration. The two otolithic organs, known as the utricle and the saccule, are located within

the vestibule of the inner ear and provide information regarding linear acceleration. Each SSC connects to the utricle via a sac called the ampulla that is surrounded by a gelatinous membrane called the cupula. Within the cupula, another organ, the crista ampullaris, houses a group of hair cells that are responsible for sensing equilibrium. Both the SCC and the otolith are filled with a fluid called endolymph that plays an important role in the excitation and inhibition of vestibular sensory receptors often referred to as hair cells. During head motion, the endolymph deflects the hair cells on one side causing excitation of these sensory receptors, while the sensory receptors on the contralateral side are inhibited. The asymmetric increase in neural excitation on one side and the reduction of neural excitation on the other side initiates a process whereby specific nerve impulses are sent to the brain and spinal centers to maintain balance (Britannica, 2008).

When this asymmetric input from the vestibular system reaches the brain, it causes conjugate smooth eye movements that are equal in magnitude and opposite in direction to the movement of the head in a healthy vestibular system (Barber & Sharpe, 1988; Sharpe & Barber, 1993). In order to transfer gaze back onto the visual target, slow-phase eye movements are followed by fast-phase saccadic eye movements, called nystagmus, that occur in the same direction of head motion. This reflexive process, called the vestibulo-ocular reflex, allows the image to remain stationary on the retina while the head is in motion and the person is able to maintain visual stability.

Clinically, VOR function can be evaluated at different frequencies and specific tests are designed to test a specific frequency range. Currently, these tests involve looking at specific measures of the VOR as well as eye movements produced by motion of different frequencies to evaluate the vestibular system and localize the vestibular deficit.

Caloric testing, for example, evaluates the lowest testable frequency range (.002-.004 Hz) of VOR function in the clinical setting. This test involves irrigating the ears with cool and warm air or water in order to stimulate the SCC, which can produce a false sensation of motion. This false sensation of motion results in nystagmus and the nystagmus is measured to evaluate horizontal SSC function. Unlike many other laboratory tests of vestibular function, caloric testing is very useful clinically because it evaluates each (right and left) peripheral vestibular system independently.

In addition to caloric testing, Rotational Chair (RC) testing also evaluates the low-frequency VOR response (0.01-1.28 Hz) and the peripheral vestibular system to help determine the location of the vestibular lesion. There are two main subtests performed during rotational chair testing: sinusoidal rotation and step testing. During both tests, the patient is accelerated in a specific direction and eye movements are monitored and recorded using electro- or video-oculography to assess VOR function.

Another test, called Dynamic Visual Acuity (DVA), evaluates VOR function at approximately 2 Hz and results of this test illustrate VOR function at moderate frequencies. A comprehensive review of this test will follow.

In order to evaluate VOR function at higher frequencies, specifically unilateral function, the Head Thrust Test (HTT) is often used in the clinical setting. During the HTT, the patient is instructed to keep his/her focus on a distant visual target while the clinician quickly turns the patient's head to the right and left and examines the patient's eye movements. If the patient is able to maintain focus on the target when the head is moved quickly, the VOR is judged to be intact. If, however, the patient exhibits saccadic eye movements to maintain focus on the target with head movements to either side, that side is suspected to have a possible VOR dysfunction.

Although the authors of this paper are also interested in evaluating VOR function at higher frequencies, the HTT is not used as the evaluative technique because this test is difficult to perform for an inexperienced clinician and is thus likely to yield a large number of false negatives. Furthermore, the HTT test may be uncomfortable for patients and is not feasible in patients with cervico-spinal disease. Finally, it is also difficult to sustain the stimulus in the HTT and testing is more time consuming because pausing is necessary to create spontaneity at each thrust.

In addition to evaluating VOR function at different frequencies, laboratory studies have also been conducted to better understand the actual mechanisms contributing to the stabilization of images on the retina while in motion. Primarily, these studies evaluate the gain of the VOR, defined by the ratio of eye velocity over head velocity. A VOR gain value of one implies that the eyes and head are 180 degrees out of phase with each other and the person is able to maintain visual stability in motion.

In one such study, for example, Meiry's (1971) findings (as cited in Vercher, Gauthier, Marchetti, Mandelbrojt, & Ebihara, 1984) showed that the VOR gain is close to one in the low frequency range, decreases slowly toward .5 around 6 to 8 Hz (as cited in Carpenter, 1977) and increases continuously up to values of 2.5 or 3 around 25 to 30 Hz (Gauthier, Piron, Roll, Marchetti, & Martin, 1984). This increase in VOR gain implies that beyond 8 Hz and up to approximately 30 Hz, the VOR is over-compensatory and is not able to keep the eyes stable in space.

It has also been found that high-frequency head rotation results in high amplitude eye oscillations in monkeys and in humans (Vercher et al., 1984). In order to determine whether these eye movements were due to the nonlinearity of the VOR system or to the mechanical

resonances of the globe, Vercher et al. (1984) quantitatively evaluated VOR gain measures and concluded that the decrease in visual stability may be due to the resonances of the globe in orbit rather than the neural substrate of VOR itself. A subsequent paper, however, suggested that this increase in VOR gain does correspond to an increase in neural activity (Ramachandran & Lisberger, 2004).

Furthermore, the human VOR has been evaluated by rotating the head around a vertical axis at a range of 0.5-30 Hz (Gauthier et al., 1984). The VOR gain and phase (timing between head and eye movements) were measured during fixation of a moving or stationary visual target in total darkness. The subjects also evaluated the degree of the perceived visual instability of the target in the two fixation conditions. The results confirmed previous findings of VOR gain and phase beyond 8 Hz: the gain curve increases to about three to four at 25-30 Hz while the phase curve does not change. This study further illustrates the perceptual drop experienced as a result of over-compensatory VOR contribution. While these studies evaluate VOR function only up to approximately 30 Hz, the authors of this paper are interested in investigating VOR function at even higher frequencies.

Importantly, the functional capacity of the VOR in helping stabilize images on the retina during head motion is influenced by many factors. One such factor is whether the head motion is active or passive. In addition to the Head Thrust Test (passive motion), the Head Autorotation Test (HART) (active motion) can also be used to evaluate VOR function in the clinical setting. During the HART test, the patient actively moves his/her head at a constant monitored frequency and is instructed to focus on a distant visual target while the gain and phase measures are evaluated. These two tests yield different results when patients with unilateral vestibular loss (UVL) are evaluated (Della Santina, Cremer, Carey, & Minor, 2002). Evaluating VOR gain, it

was found that although both testing paradigms do successfully distinguish between normal subjects and those with UVL, self-generated predictable head movements are less accurate than passive unpredictable head movements in detecting unilateral vestibulopathy. It was noted that this may be due to preprogramming that can enhance VOR function during predictable head motion. Thus, it has been shown that in order to accurately evaluate VOR function, a passive testing paradigm, such as that used in the standard 2 Hz DVA test, should be used in the clinical setting when evaluating patients with possible vestibular loss.

A similar study evaluated the degree to which DVA testing can detect and lateralize a unilateral vestibular dysfunction (Tian, Shubayev, & Demer, 2001). Visual acuity in motion was assessed in normal subjects and those with unilateral vestibular loss using predictable and unpredictable whole-body rotation. Random orientations of the letter "E" were presented at a distance of 6 meters and a computerized forced-choice method was employed. Results revealed no significant difference in DVA scores between normal subjects and those with unilateral vestibular loss when predictable rotation was used. During unpredictable rotation and optotype presentation time of only 75 ms or 300 ms, however, unilaterally vestibulopathic subjects experienced a significant degradation in dynamic visual acuity. This decrease in DVA performance was more significant with 75 ms presentation time than with 300 ms presentation time. Further analysis revealed accurate detection and lateralization of unilateral vestibulopathy using a 75 ms presentation interval and unpredictable transient rotations with peak accelerations up to 2800°/s. The authors suggest that protocols involving DVA testing in predictable conditions should incorporate methods that help overcome the compensation provided by predictive eye movements.

As described earlier, one way to evaluate the function of the vestibular system is to look at eye movements called nystagmus. Because nystagmus occurs as a result of specific conditions or disorders, a clinician will perform various tests to elicit these eye movements in order to evaluate vestibular function in symptomatic patients. Recently, vibratory stimulation applied either to the mastoid bone or the sternocleidomastoid (SCM) muscle has been incorporated into the diagnostic test battery for evaluating high-frequency VOR dysfunction in patients exhibiting symptoms of Superior Semicircular Canal Dehiscence (SSCD). This type of stimulation has successfully elicited nystagmus in healthy subjects as well as subjects with vestibular disorders. When vibration is applied to the vertex, bilateral mastoid, and bilateral suboccipital areas of patients with known SSCD, a distinct torsional and/or vertical vibration-induced nystagmus (VIN) is seen (White, Gordon, & Ruggieri, 2007), illustrating that vibratory stimulation is a sensitive screening tool for evaluating deficits associated with SSCD.

A vibratory stimulus has also been used to diagnose Vestibular Neuritis (VN) (Park, Shin, & Shim, 2007). Hand-held vibratory stimulation of 100 Hz applied to the mastoid bone and SCM muscles of healthy subjects and patients with unilateral vestibular neuritis (UVN) resulted in VIN in normal subjects and those exhibiting UVN, although the induced nystagmus from these two groups differed in direction and magnitude. Park et al. (2007) proposed two different mechanisms responsible for generating VIN in healthy subjects and patients exhibiting UVN:

> In UVN patients, vibration applied to the mastoid bone and/or SCM muscles can result in a direct vibratory stimulation of the intact vestibular receptors, while VIN in normal subjects occurs because vibration stimulates muscle spindle afferent fibers which cause normal subjects to falsely perceive lengthening of the vibrated muscle and the illusory movement of the joint. (p. 196)

All subjects also underwent caloric testing to evaluate the sensitivity of VIN in characterizing unilateral dysfunction. In patients with UVN, the direction of slow phase velocity (SPV) was consistently toward the affected side and SPV increased as a function of unilateral weakness found during caloric testing (Park et al., 2007). For these reasons, the use of vibratory stimuli in evaluating patients with suspected unilateral vestibular neuritis is recommended.

Similarly, Ohki, Murofushi, Nakahara, & Sugasawa (2003) also evaluated VIN in 100 patients with unilateral vestibulopathy using a 100 Hz vibratory stimulus applied to the mastoid and forehead areas. Patients also underwent head-shaking nystagmus (HSN) testing, caloric testing and Vestibular Evoked Myogenic Potential (VEMP) testing. VIN was found in 60% of the patients and was directed toward the unaffected side in all patients except those with possible and/or diagnosed Meniere's disease. Importantly, it was found that the nystagmus was more often induced by vibrating the mastoid rather than the forehead. Results also revealed that HSN was found in 43% of the patients and was evoked in most patients who exhibited a caloric weakness of more than 50%. Thus, in agreement with previous studies, VIN was significantly related to the degree of unilateral weakness found during caloric testing and thus to the degree of horizontal SCC dysfunction. Finally, 18 of 24 patients who had an absent VEMP on the affected side also showed VIN and the amount of VIN was therefore directly related to the degree of saccular function as well. Because it is often unfeasible to perform caloric or VEMP testing at bedside, VIN testing is a practical and simple technique for evaluating potential asymmetries in peripheral vestibular function.

Symptomatic subjects may be evaluated using a battery of tests, including the DVA test or the Dynamic Illegible E (DIE) test. Both of these tests evaluate VOR function by comparing a person's ability to read an eye chart with the head still and the head in motion. Typically, a

standard Snellen eye chart is used during 2 Hz DVA testing while a specialized eye chart of E's

is used for the DIE test. Scoring of these tests varies depending on the purpose of testing and the

setting. In clinical settings, where the purpose of visual acuity assessment is to identify possible

pathology, the effect of specific conditions on visual acuity is scored as "lines lost." Research

studies, however, that evaluate the effects of motion on visual acuity using statistical tests, often

utilize the LogMAR scale, which converts the geometric scale of a standard eye chart into a

linear scale. The LogMAR scale measures visual acuity loss with positive values indicating

vision loss and negative values indicating normal or better visual acuity. The LogMAR scale is

used more frequently in statistical calculations because it systematically quantifies clinical

findings of "lines lost" found during the DVA and DIE tests. Several studies have established

the criteria for normal and abnormal VOR function using the 2 Hz DVA and DIE tests. Utilizing

the "lines lost" and LogMAR scoring methods, respectively, two studies found that a loss of less

than 2 lines during these tests corresponds to normal vestibular function while a loss of more

than 2 lines corresponds to impaired vestibular function (Longridge & Mallinson, 1987; Goebel,

Tungsiripat, Sinks, & Carmody, 2006).

As mentioned previously, many symptoms arise as a result of dizziness, and without

proper diagnosis and management, these side effects can lead to serious debilitation and safety

hazards. One common side effect of dizziness is oscillopsia or blurred vision resulting from an

inability to maintain focus while in motion. For obvious reasons, this can have devastating

effects on one's safety. For example, a person experiencing oscillopsia may be unable to read an

important road sign while running. In a healthy vestibular system, the VOR helps maintain

visual stability in motion. In the presence of a vestibular disorder, however, the VOR system

may be impaired causing visual instability in motion.

Many laboratory studies have been conducted to evaluate the utility of the DVA test and its ability to assess VOR dysfunction by quantifying oscillopsia. One such study attempted to relate oscillopsia to vestibular impairment by looking at DVA scores of 13 healthy adult volunteers and two patients with complete peripheral vestibular loss (Demer, Honrubia, & Baloh, 1994). Normal subjects wore telescoping spectacles which "magnify the visual effects and overwhelm normal visual-vestibular interactions." (p. 340) The magnified visual effects produce retinal image instability that results in oscillopsia in normal subjects and parallels the situation faced by patients with peripheral vestibular loss. Both patients exhibiting complete vestibular loss had absent rotational or caloric vestibular responses and both complained of blurred vision during walking. Visual acuity was measured with head stationary and optotype in motion as well as with the optotype stationary and head in motion. DVA for both optotype and head motion were found to be degraded when the velocity of the image on the retina exceeded 2 º/s, in healthy and in patient subjects. Additionally, in both patients with complete vestibular loss, DVA was significantly degraded during head motion. Thus, DVA can quantitatively characterize the functional impact of an impaired VOR in patients with total peripheral vestibular loss. Although a computerized system was used for optotype presentation, it was noted that a feasible alternative to computerized equipment is the use of a printed vision testing chart which can be easily obtained in most clinical settings.

Similar results were found in a study that evaluated the sensitivity, specificity, and reliability of computerized DVA in order to investigate the functional impact of vestibular deficits (Herdman et al., 1998). The study was performed on healthy subjects as well as patients with unilateral and bilateral vestibular loss (UVL and BVL). Sensitivity was found to be 94.5% and specificity was found to be 95.2%. Also, high positive and negative predictive values were

found during testing. A high predictive value means that a large number of those individuals who obtain abnormal results during the DVA test will truly have a vestibular dysfunction while a high negative predictive value means that a large number of those individuals who obtain normal results during DVA testing will not have a vestibular dysfunction. DVA testing can, therefore, distinguish between healthy subjects and patients with vestibular dysfunction and can also distinguish between UVL and BVL patients. For these reasons, the DVA test can be used as a reliable screening tool for evaluating patients with possible VOR dysfunction and other vestibular complaints.

Notably, several variations of the DVA test exist in the clinical setting. One such test is called the Gaze Stabilization Test (GST) which is used to evaluate suspected unilateral vestibular dysfunction. Gaze stabilization is evaluated by measuring maximum head velocity in degrees per second that a subject is able to maintain fixation of a visual target 0.3 logMAR (3 lines above static acuity on a Snellen eye chart) while simultaneously moving the head. When sensitivity, specificity, and reliability of the GST were evaluated in normal subjects and in patients with unilateral vestibular dysfunction, it was found that the GST is able to distinguish between healthy subjects and patients with UVL with fair sensitivity and high specificity (Goebel et al., 2006). These results were also compared with results found during computerized DVA and indicated that computerized DVA test results of healthy subjects were significantly better than those of UVL subjects, which, in agreement with previous studies, validates the use of the GST and computerized DVA tests to diagnose vestibular dysfunction.

Although DVA testing is used to assess the function of the two horizontal semicircular canals, a recent study evaluated whether DVA can be used to measure individual SCC function during passive high-acceleration head rotations in the plane of the SCC being tested (Schubert,

Migliaccio, & Della Santina, 2006). In this study, DVA scores were compared with the corresponding VOR gain using a 3-D scleral search coil technique. These measures were evaluated in normal subjects, subjects tested after surgical plugging of a single SCC as a treatment for SSCD, and subjects who had undergone unilateral vestibular neurectomy. Head-thrust DVA (htDVA) scores were found to be inversely proportional to the SCC VOR gain measured using the Head Thrust Test and 3-D scleral coils. Subjects with normal vestibular function obtained similar htDVA scores for all six SCC tested. Subjects tested after surgical plugging of one SCC obtained scores that were similar to the normal group on all SCC except the plugged SCC, which yielded significantly poorer htDVA scores. Finally, subjects who had undergone unilateral vestibular neurectomy obtained significantly poorer htDVA scores when testing involved rotations stimulating the ipsilesional rather than the contralesional SCC. It was therefore concluded htDVA testing, which does not require expensive equipment and scleral coil placement, can be used in the clinical setting to evaluate function of individual semicircular canals.

Additionally, motion is unavoidable in daily living and results from common activities including walking or running, driving a car, and participating in sports. Impaired mobility resulting from symptoms of imbalance significantly impairs one's quality of life and while the aforementioned activities may seem quite basic, a person exhibiting oscillopsia may have great difficulty performing these tasks. It is therefore important to evaluate the effects of an impaired VOR system on a person's visual acuity, specifically visual acuity in motion. DVA scores obtained during standing and walking from healthy subjects and patients with severe BVL showed that patients' overall performance was significantly poorer while standing and while walking compared to the overall performance of normal subjects (Hillman, Bloomberg,

McDonald, & Cohen, 1999). These results illustrate that patients with an impaired VOR system are unable to compensate for the motion and maintain visual acuity while walking. Thus, the clinical utility of the DVA test may lie in its ability to evaluate the severity of VOR impairment by quantifying oscillopsia experienced while in motion.

Interestingly, multiple studies have also investigated DVA scores of patients who present with symptoms of dizziness but obtain normal results on clinical tests of vestibular function (Schubert, Herdman, & Tusa, 2002; Roberts & Gans, 2007). These types of subjects, categorized as experiencing "non-vestibular dizziness," obtained horizontal DVA scores that were poorer compared to baseline condition for the smallest font size only (Roberts et al., 2007). This finding illustrates that on standard 2 Hz DVA tests, patients experiencing non-vestibular dizziness perform almost as well as asymptomatic subjects. The authors of the current study are also interested in investigating the effects of high-frequency stimulation on the vestibulo-ocular reflex of such patients who are symptomatic but obtain normal scores on laboratory tests of vestibular function.

In summary, the DVA test is a reliable and sensitive tool in distinguishing normal subjects from those exhibiting vestibular dysfunction that results from an impaired VOR. However, despite these findings, the use of computerized equipment makes it difficult to be performed in a typical clinical setting or at bedside. Computerized equipment, while definitely effective, is very expensive and may not always be available. Because it may not be financially and physically feasible to set up computerized DVA and rotary chair equipment in every clinical setting, the authors of this study propose a sensitive yet more affordable system to evaluate the functional effects of an impaired VOR. This testing protocol consists of a hand-held vibratory stimulator and a standard Snellen eye chart. Also, although previous studies have been clinically

useful in improving the DVA technique, much less attention has been devoted to the evaluation

of the VOR at higher frequencies. Specifically, natural head movement occurs at significantly

higher frequencies than 2 Hz and many patients complain of balance symptoms only at higher

frequencies. Therefore, a need exists to systematically evaluate the ability to maintain visual

acuity at high frequencies of motion.

The authors of this study have designed a testing protocol to test high-frequency VOR

function by combining vibration-induced nystagmus testing and dynamic visual acuity testing

both of which are already being used in the clinical setting. This study assesses DVA using 60

Hz vibration applied to the mastoid bone (60 Hz DVA) and compares these results to Static

Visual Acuity (SVA) and 2 Hz DVA scores. The hypothesis of this study is that different

motions of the head might identify objective abnormalities in patients complaining of dizziness

who obtain normal results on other tests of vestibular function including caloric testing and 2 Hz

DVA. The vibration-induced 60 Hz DVA test will therefore improve the ability to identify and

treat patients with selective high-frequency vestibular loss and will add to the current test battery

used to evaluate patients with subjective imbalance.

METHODS

In total, 32 subjects participated in this study. All participants were informed regarding

their participation and written informed consent was obtained from each participant prior to

enrollment. Twenty-one healthy participants with no prior history of dizziness or imbalance

were recruited as controls (age range: 22-35 years; mean age: 24.5 years SD ± 2.64). The

inclusion criteria for the control group subjects were: 1) willingness to participate in DVA testing

following 2 Hz head motion and 60 Hz vibratory stimulation, and 2) no signs or symptoms of

cervical spine problems and/or a known history of cervico-spinal disease. Eleven subjects with

known vestibular complaints who had previously undergone caloric testing to evaluate vestibular

function were recruited as the experimental group (age range: 27-62; mean age: 48 years SD ±

10.29). Inclusion criteria for the experimental group subjects were: 1) willingness to participate

in DVA testing following 2 Hz head motion and 60 Hz vibratory stimulation, 2) no signs or

symptoms of cervical spine problems and/or a known history of cervico-spinal disease, as well as

3) documented history of dizziness and/or imbalance, and 4) documented participation in and test

results obtained during caloric testing. These symptomatic subjects were recruited from the

patient population of practicing Otolaryngologists at the Center for Advanced Medicine at

Washington University School of Medicine. Each testing session consisted of three main

subtests and lasted approximately 15 minutes.

The three subtests were a) Static Visual Acuity (SVA) testing, b) 2 Hz Dynamic Visual

Acuity (2 Hz DVA) testing, and c) 60 Hz Dynamic Visual Acuity (60 Hz DVA) testing. During

SVA testing, each subject was instructed to read all of the letters on a standard Snellen eye chart,

at a distance of 10 feet, starting with the largest letter at the top of the chart. The experiment was

first performed to evaluate the differences in scores obtained using a 20-ft eye chart versus a 10-

ft eye chart. Because no differences in results were found between the two eye chart distances,

the 10-ft eye chart was chosen strictly for practical reasons. Also, in order to account for the

learning effect, three different eye charts were used, such that a different eye chart was used for

each subtest. Each line on the eye chart corresponds to a specific visual acuity at 10 ft and is

assigned a line number 1 though 11. For example, on Chart 1, Line 1 consists of the letter E and

corresponds to a visual acuity of 10/100. On the same chart, Line 10 consists of eight letters and

corresponds to a visual acuity of 10/6.5. When the subject could not longer identify at least 50% of the letters on a specific line, that line was recorded as the subject's SVA score.

During the 2 Hz DVA subtest, the subject's head was rotated passively at approximately 2 Hz and the subject was again instructed to read the letters on the eye chart. As with SVA testing, when the subject could no longer identify at least 50% of the letters on a specific line, that line was recorded as the subject's 2 Hz DVA score.

During the third subtest, a vibratory stimulus of approximately 60 Hz, as measured by a rate meter and an oscilloscope, was applied to the subject's mastoid and the subject was asked to read the letters on the eye chart again. Importantly, the mastoid bone was chosen as the stimulation site because previous studies have shown that nystagmus can be elicited when vibration is applied to this area. As with previous subtests, visual acuity was recorded as the last line which the subject could successfully identify 50% of the letters. This line was then recorded as the subject's 60 Hz DVA score.

Following these subtests, the three visual acuity scores were compared to evaluate the change in visual acuity following 2 Hz and 60 Hz head motion. First, the SVA test score was compared with the 2 Hz DVA test score by subtracting the 2 Hz DVA score from the SVA score. For example, Subject 1 obtained a SVA score of 7 and a 2 Hz DVA score of 5. Subtracting 5 from 7 yielded a score of 2, illustrating that with head motion of approximately 2 Hz, Subject 1 lost 2 lines of visual acuity. This subject's 60 Hz DVA score of 6 was also subtracted from his SVA score of 7 to evaluate high-frequency VOR function. Subtracting 6 from 7 yielded a score of 1 line lost. This procedure was used for asymptomatic subjects as well as those with reported subjective imbalance.

RESULTS

In total, 21 healthy subjects without known dizziness or imbalance served as controls during this study. Visual acuity scores of the control group were analyzed to evaluate the effects of 2 Hz and 60 Hz motion on visual acuity. A one-tailed paired t-test, performed for each condition, SVA vs. 2 Hz DVA, SVA vs. 60 Hz DVA, and 2 Hz vs. 60 Hz DVA, revealed three important findings at a high level of significance (p<0.001). First, it was found that asymptomatic subjects' 2 Hz DVA scores were significantly lower than their corresponding SVA scores. Also, asymptomatic subjects' SVA scores were significantly different from their 60 Hz DVA scores. Finally, asymptomatic subjects' 2 Hz DVA scores were significantly different from their 60 Hz DVA scores. From these results, it can at least be inferred that the two types of motion have different effects on VOR function.

Figures 1, 2, and 3 represent asymptomatic subjects' SVA scores, 2 Hz DVA scores, and 60 Hz DVA scores, respectively. Figure 1 lists subjects based on their SVA scores, from lowest to highest score, in lines identified correctly. This same subject order is maintained in Figures 2, 3, and 4, but visual acuity is recorded as lines lost.

Static Visual Acuity is defined as the number of lines identified correctly on a Snellen eye chart with the head still. SVA scores in asymptomatic subjects ranged from 7 to 11 lines identified correctly.
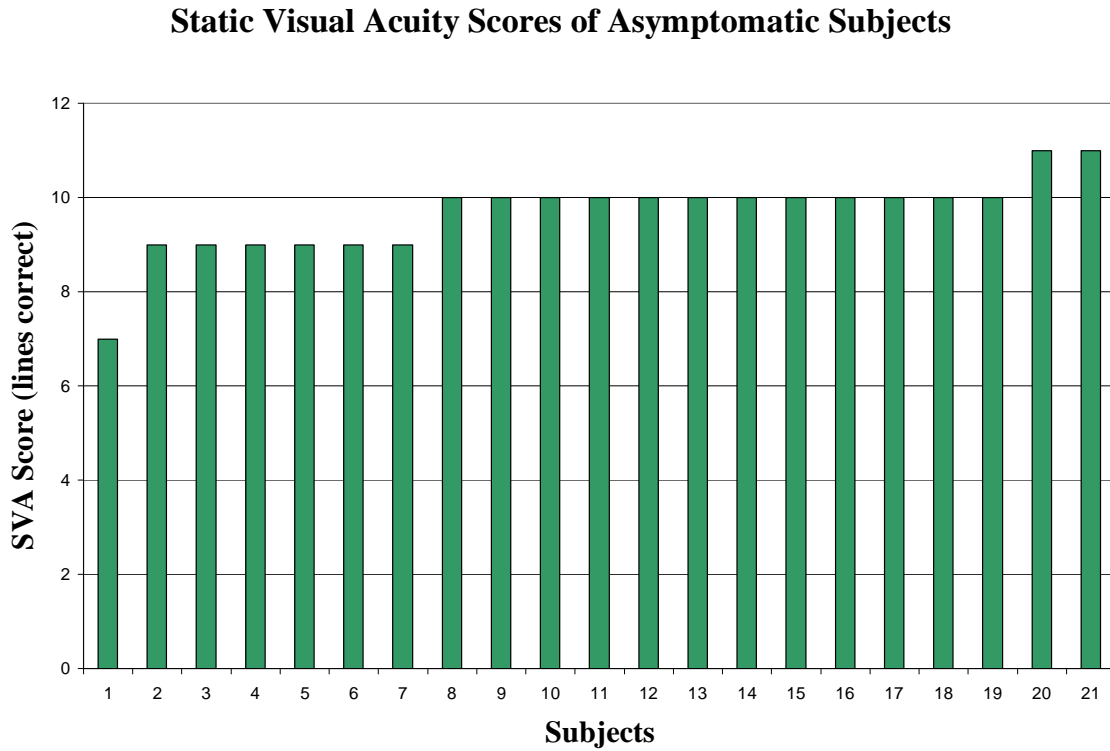
Static Visual Acuity Scores of Asymptomatic Subjects

FIGURE 1: SVA scores of asymptomatic subjects.

2 Hz Dynamic Visual Acuity is defined as the number of lines identified correctly in the static condition minus the number of lines lost with the head being moved passively at 2 Hz. The mean and standard deviation (SD) of 2 Hz DVA scores of asymptomatic subjects in this study was approximately 2.5 ± 0.75. Assuming that 95% of the asymptomatic subjects lie within 2 SD of the mean (95% Confidence Interval), it can be said that the normal scores on the 2 Hz DVA test fall between 0.977 and 3.975 or below 4 lines lost. Therefore, subjects who lost more than 4 lines during the 2 Hz DVA test were abnormal on this test.
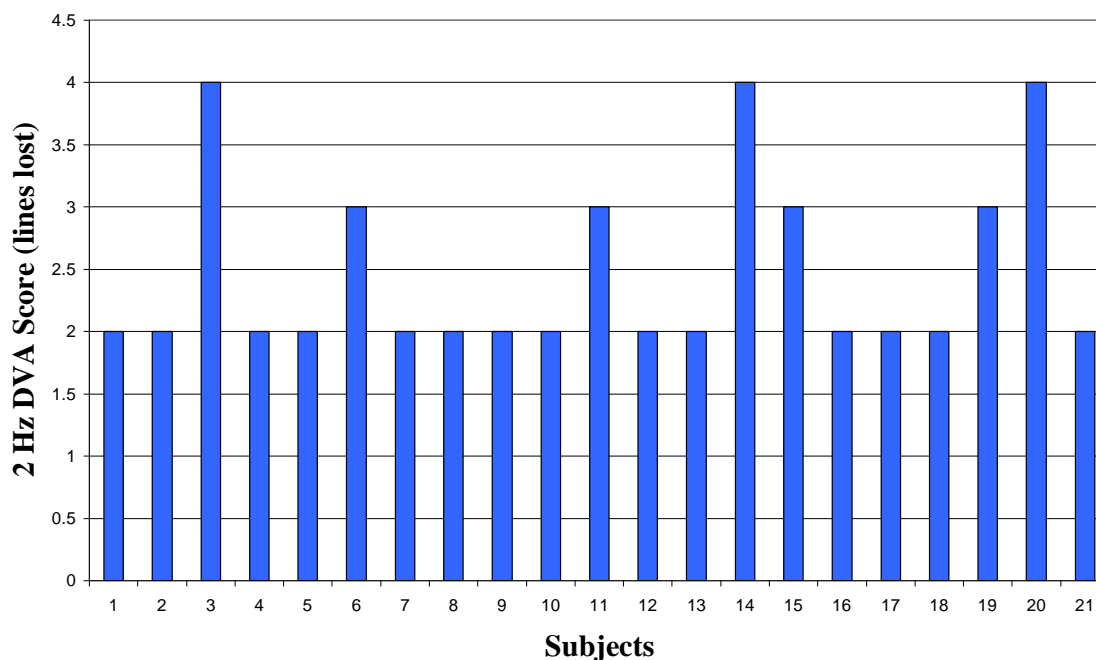
2 Hz DVA Scores of Asymptomatic Subjects

FIGURE 2: 2 Hz DVA scores of asymptomatic subjects.

60 Hz Dynamic Visual Acuity is defined as the number of lines identified correctly in the static condition minus the number of lines lost with the head vibrated at 60 Hz. The mean and SD of asymptomatic subjects' scores on this test was approximately 1.14 ± .85. Again, assuming that 95% of the asymptomatic subjects lie within 2 SD of the mean, normal scores on the 60 Hz DVA test fall in the range -.557 and 2.84, or less than 3 lines lost. Therefore, subjects who lost more than 3 lines during 60 Hz DVA were abnormal on this test.
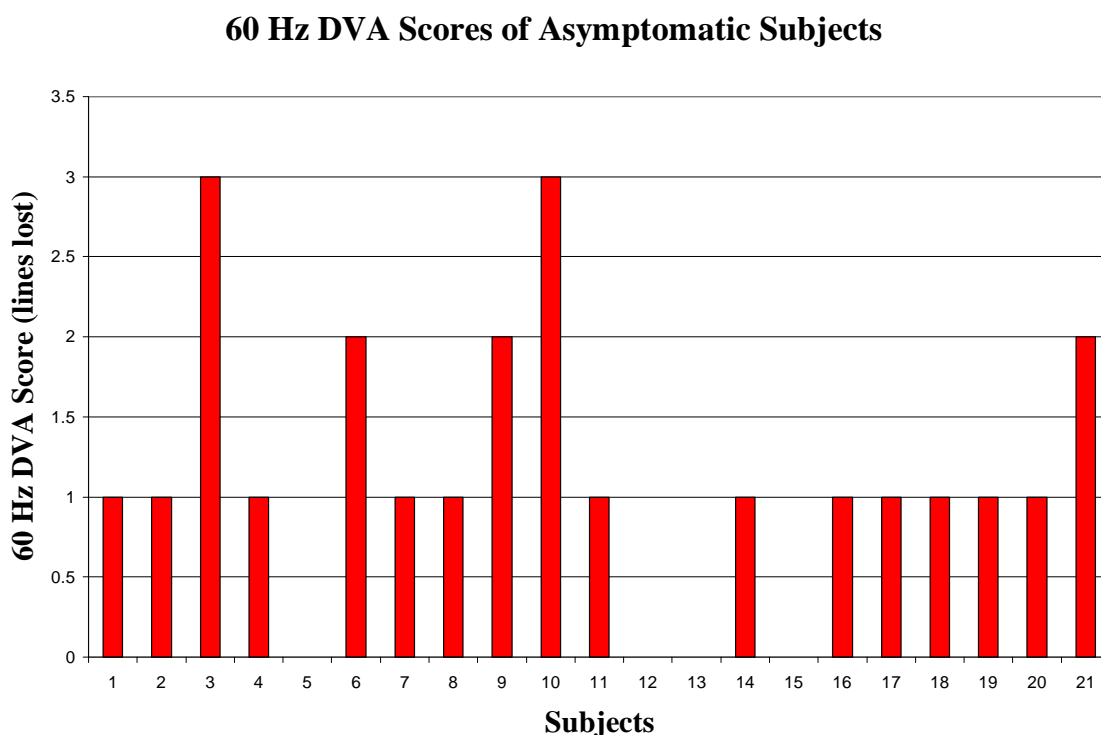
60 Hz DVA Scores of Asymptomatic Subjects

FIGURE 3: 60 Hz DVA scores of asymptomatic subjects.

Figure 4 represents the 2 Hz DVA score and 60 Hz DVA score of each asymptomatic subject. 2 Hz head motion yielded more significant visual acuity degradation than 60 Hz head motion in 20 of 21 asymptomatic subjects.

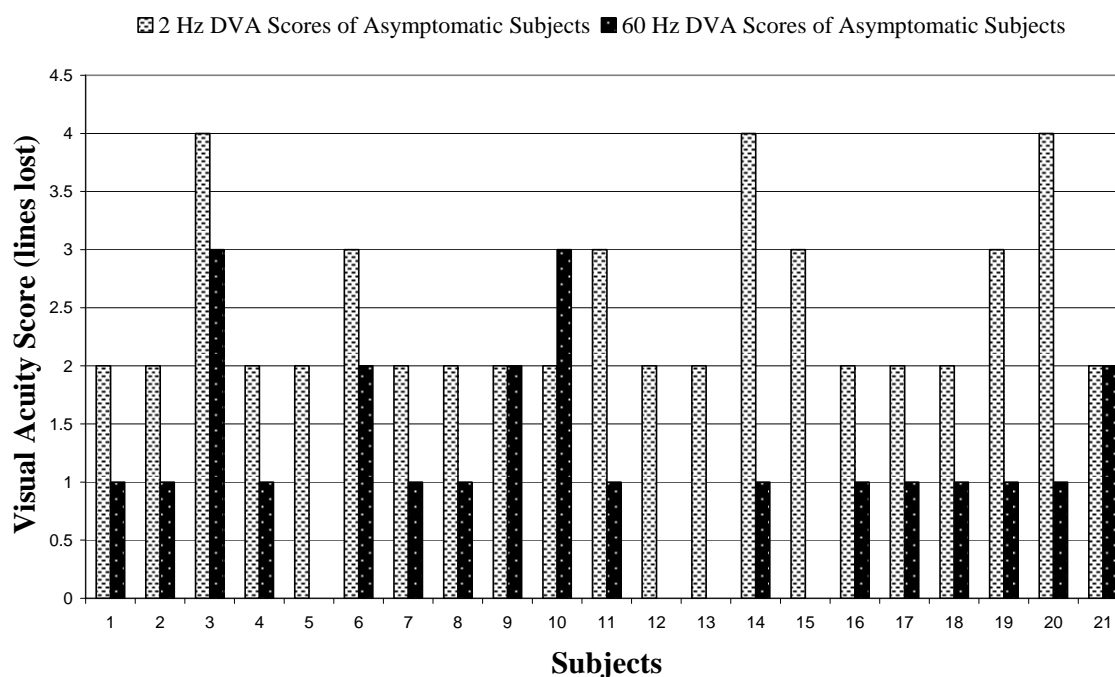**2 Hz and 60 Hz DVA Scores of Asymptomatic Subjects**

FIGURE 4: 2 Hz and 60 Hz DVA scores of asymptomatic subjects.

By testing and analyzing the visual acuity scores of asymptomatic subjects, the authors of this study were able to determine the normal range of scores for the SVA, 2 Hz DVA and 60 Hz DVA tests. Therefore, even though previous studies have determined that a loss of more than 2 lines on the 2 Hz DVA test signifies a vestibular pathology, the findings of this study illustrate that a loss of 4 lines or more on the 2 Hz DVA test and a loss of 3 lines or more on the 60 Hz DVA test signifies pathology.

Due to the small sample size, statistical tests could not be performed on visual acuity scores of the experimental group. Therefore, the authors report and analyze visual acuity scores

of the experimental group graphically and descriptively in order to make inferences regarding the

DVA performance of symptomatic subjects following 2 Hz and 60 Hz head motion. Table 1 lists

symptomatic subjects and their corresponding demographic information.

UVD: Unilateral Vestibular Dysfunction   BVD: Bilateral Vestibular Dysfunction

Subject Number	Age (y) mean: 48	Gender (M/F)	Caloric Test Asymmetry (%)	Normal/UVD/BVD Caloric Results
1	62	M	NA	BVD
2	37	M	NA	Normal
3	27	F	8	Normal
4	50	F	14	Normal
5	43	F	75	UVD
6	59	M	78	UVD
7	48	F	10	BVD
8	48	F	6	Normal
9	52	F	26	Normal
10	43	F	5	Normal
11	58	F	84	UVD

TABLE 1: Symptomatic subject demographics.

Visual acuity scores of the experimental group were first analyzed to establish whether

those subjects who were identified as abnormal during caloric testing were also identified as

abnormal during the 2 Hz DVA and 60 Hz DVA tests (Figures 5 & 6). At the Washington

University Center for Advanced Medicine, where all of the subjects in the experimental group

were tested, a 30% caloric difference between the right and left ears is considered significant.

Also, visual acuity scores of the experimental group were analyzed to establish whether those

subjects who were identified as abnormal on the 2 Hz DVA test were also identified as abnormal

on the 60 Hz DVA test (Figure 7).

Using the criteria of 4 or more lines lost on 2 Hz DVA as the threshold for abnormal results, the data in Figure 5 show that among the 8 symptomatic subjects with normal caloric responses, 2 subjects obtained abnormal 2 Hz DVA scores (Subjects 1 and 8).

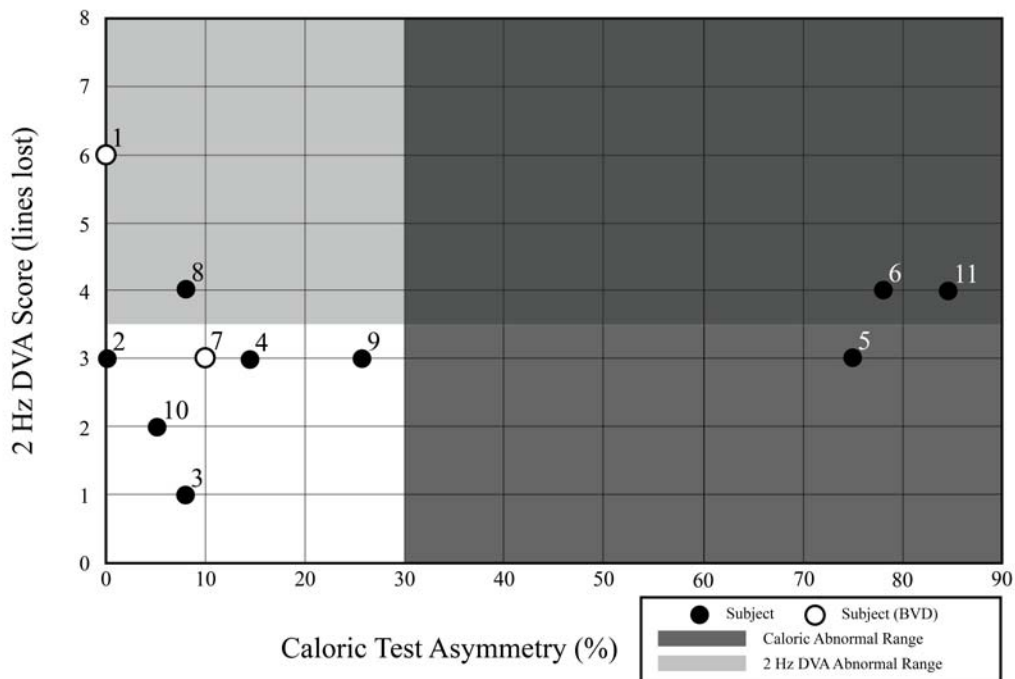Caloric Test Asymmetry & 2 Hz DVA Scores of Subjectively Imbalanced Subjects

FIGURE 5: Relationship between caloric test results and 2 Hz DVA scores of subjectively imbalanced subjects.

Additionally, in analyzing the 60 Hz DVA scores of the asymptomatic subjects, it was concluded that a score of 3 or more lines lost signifies abnormal 60 Hz DVA results. Using this criterion, Figure 6 illustrates that among the 8 symptomatic subjects with normal caloric responses, 3 subjects obtained abnormal 60 Hz DVA scores (Subjects 2, 4, and 8).
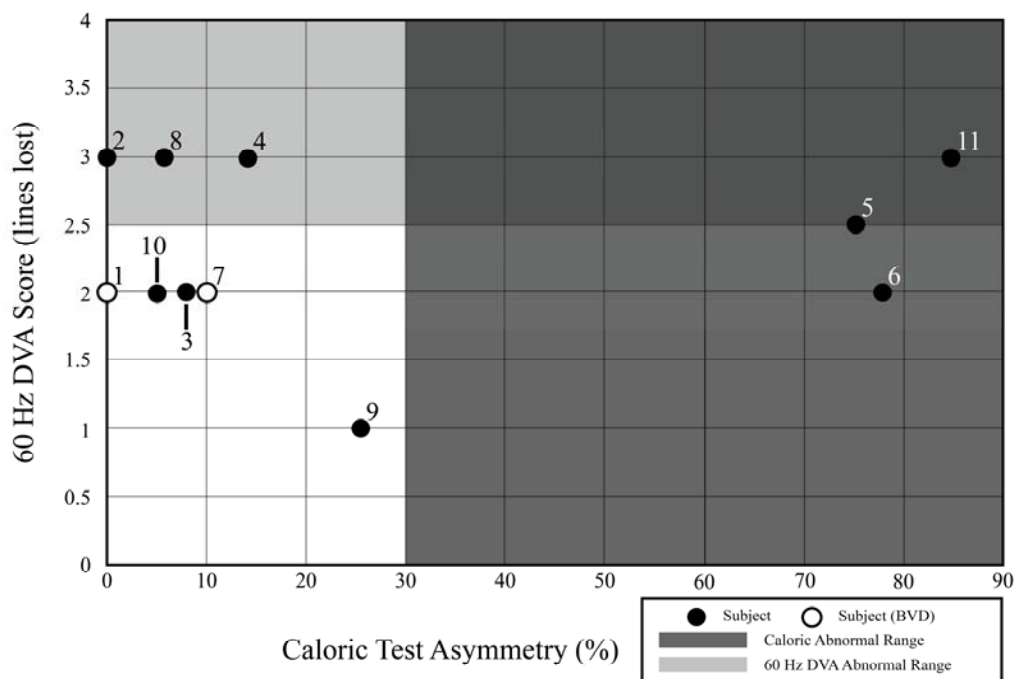

FIGURE 6: Relationship between caloric test results and 60 Hz DVA scores of 11 subjectively imbalanced subjects.

Finally, in comparing 2 Hz and 60 Hz DVA results of the symptomatic subjects, Figure 7 illustrates that among the seven symptomatic subjects with normal 2 Hz DVA scores, 3 subjects obtained abnormal 60 Hz DVA scores (Subjects 2, 4, and 5).
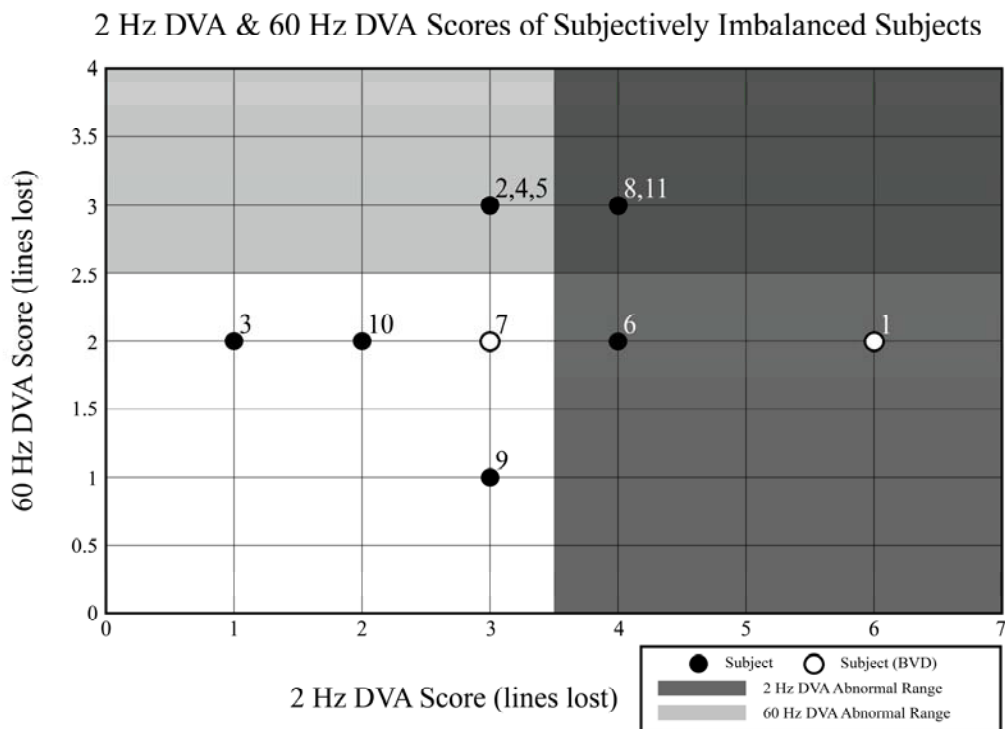

FIGURE 7: Relationship between 2 Hz DVA and 60 Hz DVA scores of 11 subjectively imbalanced subjects.

DISCUSSION

The initial hypothesis of this study was that the 60 Hz DVA test might identify symptomatic subjects as abnormal even though these same subjects obtained normal results during caloric testing and the 2 Hz DVA test. Although the small sample size of the experimental group in this study limited the ability to perform statistical analyses on symptomatic subjects, the initial data presented suggest that the original hypothesis might be correct.

The graphed data presented earlier illustrate that both asymptomatic subjects and subjects with known imbalance obtain different results on the 2 Hz and 60 Hz DVA tests, illustrating that these two tests have different effects on VOR function and that the two tests do identify separate patient groups. The results also indicate that three subjectively imbalanced subjects who obtained normal results during caloric testing actually obtained abnormal results during the 60 Hz DVA test. Interestingly, three symptomatic subjects also obtained abnormal 60 Hz DVA scores even though their 2 Hz DVA scores were normal. It is therefore the authors' conclusion that the 60 Hz DVA test does identify symptomatic subjects as abnormal and should be considered a valuable clinical tool.

By testing and analyzing the visual acuity scores of asymptomatic subjects in this study, the normal range of scores for SVA, 2 Hz DVA and 60 Hz DVA was calculated. Even though previous studies have determined that a loss of more than 2 lines on the 2 Hz DVA test signifies a vestibular pathology, data analysis in this study incorporated a loss of 4 lines or more to signify pathology on the 2 Hz DVA test and a loss of 3 or more lines to signify pathology on the 60 Hz DVA test. The results of this study illustrate that the group of subjects scoring abnormally on the 60 Hz DVA test is not identical to that scoring abnormally during caloric testing or the 2 Hz DVA test. This indicates that the 60 Hz DVA test gives complementary but not redundant information.

The results of this study are consistent with previous findings that rapid, high-frequency head movements identify different patient groups than self-generated, predictable head movements in tests evaluating VOR function (Halmagyi, Black, Thurtell, & Curthoys, 2003; Schubert et al., 2006). Although the data in this study are consistent with these findings, the testing paradigm presented in this study differs from those used in previous studies. The authors

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suggest that the 60 Hz DVA testing paradigm is not only easily administered, but is also well tolerated by patients and likely not highly dependent on the person administering the test.

Interestingly, the authors of this study were surprised to find that a large group of subjects had a more severe degradation in visual acuity under the 2 Hz condition as compared with the 60 Hz condition. Although the exact reason for this finding is unknown, it is suggested that this may be due to eye inertia and retinal slip velocity. A previous study evaluating DVA of normal subjects during vertical optotype and head motion found that the visual system is able to tolerate retinal slip of up to 2°/sec or less without an appreciable decrease in DVA and that retinal slip above 2°/sec causes a significant degradation in dynamic visual acuity (Demer et al., 1994). It may be that the 60 Hz vibration, despite being a higher frequency, actually causes less angular movements of the eyes and therefore does not cause as much visual acuity degradation as would otherwise be expected.

It should be noted that the 60 Hz DVA test presented in this study is not a "pure" test of vestibular function for two important reasons. First, the 60 Hz DVA test is psychophysical, requiring integration of visual cues at the cortical level. The most standard tests of vestibular function, such as caloric testing and rotational chair testing, are entirely reflexive. Second, this test is performed in a well-lit environment. In the light, the VOR reflexive response is suppressed and therefore it can be inferred that the results presented here are not purely vestibular. Notably, both of these caveats also apply to well-accepted tests such as the standard 2 Hz DVA test. While neither one of these factors makes this test less relevant, interpretation of the results should be made with this in mind.

Furthermore, the evaluation of the high-frequency range of VOR function using vibration is a new concept and it is unknown which structures are truly being evaluated. Perhaps in

addition to the horizontal SSC which are normally evaluated during the standard 2 Hz DVA test, this vibratory stimulus, which may provide motion in multiple axes of rotation, may also be testing the function of the otolithic organs. If this is indeed the case, the otolithic organs, which may be intact even if the horizontal VOR is impaired, may be contributing to the less-than-otherwise expected significant degradation in visual acuity following 60 Hz head vibration.

There are also several significant limitations of this study that should be acknowledged. One such limitation was the inability to recruit more symptomatic subjects and the resultant small sample size. Future studies should be conducted utilizing larger control and experimental groups and should account for variables such as age and gender in order to statistically evaluate the effects of different types of motion on visual acuity in these subject groups. Furthermore, future studies involving DVA testing in asymptomatic subjects should incorporate multiple tests of vestibular function, such as caloric testing, in order to develop a more comprehensive database of normative data.

Another limitation of this study is that although the student administering the 2 Hz and 60 Hz DVA tests was trained on the testing techniques, it is difficult to monitor factors such as motion velocity and stimulus placement without computerized equipment. Therefore, it is not unreasonable to attribute at least part of the differences in the results to these factors. For these reasons, it is suggested that this type of study be repeated with the use of computerized equipment so that factors like head velocity and stimulus placement can in fact be monitored throughout testing. If the limitations encountered during this study are addressed, future studies on this topic will be improved and may yield more significant results.

CONCLUSION

High-frequency vibratory stimulation applied to the mastoid of symptomatic subjects identifies some of these individuals as abnormal on the 60 Hz DVA test even though these same subjects were identified as normal during caloric testing and the standard 2 Hz DVA test. The interesting findings of this study should motivate future research studies to evaluate the effects of high-frequency motion on visual acuity in subjects with subjective imbalance. This is especially critical because of the prevalence of oscillopsia among patients presenting with dizziness and/or imbalance. Further evaluating the effects of different types of motion on visual acuity in research and in clinical settings should yield more accurate clinical diagnoses and may in fact alter or even enhance current treatment protocols.

References

Barber, H., & Sharpe, J. (1988). *Vestibular disorders.* Chicago: Year Book Medical Publishers, Inc.

Della Santina, C., Cremer, P., Carey, J., & Minor, L. (2002). Comparison of head thrust test with head autorotation test reveals that the vestibulo-ocular reflex is enhanced during voluntary head movements. *Archives of Otolaryngology Head and Neck Surgery, 128(9),* 1044-1054.

Demer, J., Honrubia, V., & Baloh, R. (1994). Dynamic visual acuity: a test for oscillopsia and vestibulo-ocular reflex function. *The American Journal of Otology*, *15*(*3*), 340-347.

Gauthier, G., Piron, J., Roll, J., Marchetti, E., & Martin, B. (1984). High-frequency vestibulo-ocular reflex activation through forced head rotation in man. *Aviation, Space, and Environmental Medicine*, *55*(*1*), 1-7.

Goebel, J., Tungsiripat, N., Sinks, B., & Carmody, J. (2006). Gaze stabilization test: a new clinical test of unilateral vestibular dysfunction. *Journal of Otology and Neurotology*, *28*, 68-73.

Hain, MD, T. (2006, December 27). *Otoneurology Index*. Retrieved March 6, 2008, from http://www.dizziness-and-balance.com/index.html.

Halmagyi, G., Black, R., Thurtell, M., & Curthoys, I. (2003). The human horizontal vestibulo-ocular reflex in response to active and passive head impulses after unilateral vestibular deafferentation. *Annals of the New York Academy of Sciences, 104,* 325-336.

Herdman, S., Tusa, R., Blatt, P., Suzuki, A., Venuto, P., & Roberts, D. (1998). Computerized dynamic visual acuity test in the assessment of vestibular deficits. *The American Journal of Otology*, *19*(*6*), 790-796.

Hillman, E., Bloomberg, J., McDonald, V., & Cohen, H. (1999). Dynamic visual acuity while walking in normals and labyrinthine-deficient patients. *Journal of Vestibular Research*, *9*, 49-57.

Longridge, N., & Mallinson, A. (1987). The dynamic illegible E-test. A technique for assessing the vestibulo-ocular reflex. *Acta Oto-Laryngologica*, *103*(*3-4*), 273-279.

Movement perception. (2008). In *Encyclopedia Britannica.* Retrieved February 10, 2008, from Encyclopedia Britannica Online: http://www.britannica.com/eb/article-46637

Ohki, M., Murofushi, T., Nakahara, H., & Sugasawa, K. (2003). Vibration-induced nystagmus in patients with vestibular disorders. *Journal of Otolaryngology-Head and Neck Surgery*, *129*(*3*), 255-258.

Park, H., Shin, J., & Shim, D. (2007). Mechanisms of vibration-induced nystagmus in normal subjects and patients with vestibular neuritis. *Journal of Audiology & Neurotology*, *12*, 189-197.

Ramachandran, R., & Lisberger, S. (2004). Normal performance and expression of learning in the vestibulo-ocular reflex (VOR) at high frequencies. *Journal of Neurophysiology, 93,* 2028-2038.

Roberts, R., & Gans, R. (2007). Comparison of horizontal and vertical dynamic visual acuity in patients with vestibular dysfunction. *Journal of the American Academy of Audiology*, *18*(*3*), 236-244.

Schubert, M., Migliaccio, A., & Della Santina, C. (2006). Dynamic visual acuity during passive head thrusts in canal planes. *Journal of the Association for Research in Otolaryngology*, *7*, 329-338.

Schubert, M., Herdman, S., & Tusa, R. (2002). Vertical dynamic visual acuity in normal subjects and patients with vestibular hypofunction. *Journal of Otology & Neurotology*, *23*(*3*), 372-377.

Sharpe, J., & Barber, H. (1993). *The vestibulo-ocular reflex and vertigo.* New York: Raven Press.

Sloan, P., Coeytaux, R., Beck, R., & Dallara, J. (2001). Dizziness: state of the science. *Annals of Internal Medicine, 134(9)*, 823-832.

Tian, J., Shubayev, I., & Demer, L. (2001). Dynamic visual acuity during transient and sinusoidal yaw rotation in normal and unilaterally vestibulopathic humans. *Experimental Brain Research, 137(1)*, 12-25.

Vercher, J., Gauthier, G., Marchetti, E., Mandelbrojt, P., & Ebihara, Y. (1984). Origin of eye movements induced by high frequency rotation of the head. *Aviation, Space, and Environmental Medicine*, *55*(*11*), 1046-1050.

White, J., Gordon, B., & Ruggieri, P. (2007) Vibration-induced nystagmus as an office procedure for the diagnosis of superior semicircular canal dehiscence. *Otology & Neurotology, 28(7),* 911-916.