Nystagmus testing in intoxicated individuals

Karl Citek, O.D., Ph.D.,[a] Bret Ball, O.D.,[a] and Dale A. Rutledge, Lieutenant[b]

[a]College of Optometry, Pacific University, Forest Grove, Oregon and [b]the Oregon State Police, Wilsonville, Oregon

Background: Law enforcement officers routinely conduct psychophysical tests to determine if an impaired driver may be intoxicated or in need of medical assistance. Testing includes assessment of eye movements, using the Horizontal Gaze Nystagmus (HGN) and Vertical Gaze Nystagmus (VGN) tests, which are conducted at roadside by patrol officers. These tests previously have been validated when the subject is placed in a standing posture with head upright. However, certain conditions require that the subject be tested while seated or supine. Under these conditions, Positional Alcohol Nystagmus (PAN) could be induced and mistaken for HGN or VGN.

Methods: The study was conducted at law enforcement training academy alcohol workshops in the Pacific Northwest. Ninety-six volunteer drinkers were tested when sober and three times after drinking alcohol by 40 volunteer officers experienced in administering the tests. Blood alcohol concentration (BAC) was measured objectively with a calibrated breath analysis instrument each time a subject was tested.

Results: The number of eye movement signs observed during the HGN test at any posture increases with increasing BAC. The presence of VGN at any test posture occurs only in the presence of signs of HGN and only at high levels of impairment. PAN was most often observed at BACs of 0.08% and higher, but was never confused with the observation of HGN or VGN, regardless of test posture.

Conclusions: The HGN test administered in the standing, seated, and supine postures is able to discriminate impairment at criterion BACs of 0.08% and 0.10%. The VGN test can identify high levels of impairment at any test posture. Therefore, these tests can be used by an officer to determine if a driver is impaired, regardless of whether the driver is standing, seated, or supine.

Key Words: Alcohol, blood alcohol concentration (BAC), horizontal gaze nystagmus (HGN), impairment, law enforcement, positional alcohol nystagmus (PAN), vertical gaze nystagmus (VGN)

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In the United States, drivers impaired* by alcohol and/or drugs are responsible for more than 16,000 deaths, one million injuries, and $45 billion in costs annually.[1] As part of the attempt to reduce these human and economic tolls, law enforcement officers routinely conduct tests of eye movements to determine if a driver is under the influence of alcohol or other drugs. Alcohol, other central nervous system (CNS)-depressant drugs, inhalants, and phencyclidine (PCP) and its analogs will affect the neural centers in the brainstem and cerebellum, which control eye movements, as well as other motor, sensory, and cognitive integration areas of the brain. In addition, certain antihistamines have physiologic and cognitive effects similar to CNS-depressant drugs.

Blood alcohol concentration (BAC), also known as blood alcohol level, is either measured directly from a blood sample or estimated from a breath or urine sample. BAC is commonly reported as a percentage of alcohol weight per volume of blood. When impairment is due solely to the influence of alcohol, most states and Canadian provinces define the legal limit for passenger vehicle drivers as 0.08%, while some states still allow the higher limit of 0.10%.

Positive findings on the Horizontal Gaze Nystagmus (HGN) test have been shown to correlate highly with both BAC and cognitive impairment.[2] The American Optometric Association has previously recognized the validity and reliability of the HGN test as used by the law enforcement community.[3]

* The inability to safely operate a motor vehicle. This may be cognitive (e.g., abnormal perception of time and space) or physical (e.g., restricted use of a limb or uncorrectable vision loss).

Officers conduct the HGN test at roadside as part of the Standardized Field Sobriety Tests (SFSTs).[4-6] The HGN test assesses lack of smooth pursuit, sustained endpoint nystagmus, and induced nystagmus prior to a lateral gaze angle of 45 degrees. Recently, the Vertical Gaze Nystagmus (VGN) test has been added to the SFST training for patrol officers.[4] The VGN test assesses nystagmus induced in upgaze.

Collectively, the SFSTs are used to establish probable cause for arrest on a Driving Under the Influence (DUI) charge and subsequent request for a breath, blood, or urine sample, in order to objectively measure the BAC. These tests also are conducted by specially trained officers as part of the Drug Recognition Expert (DRE) evaluation when the presence of a drug (or drugs other than or in addition to alcohol) is suspected.[7] Results of these tests assist the officer in accurately and reliably determining the presence of CNS-depressant drugs, inhalants, and PCP.[8,9]

The procedure of the HGN test was standardized more than 20 years ago by the National Highway Traffic Safety Administration (NHTSA).[10,11] In the mid 1980's, NHTSA standardized the procedure of the VGN test as part of the DRE evaluation.[12] As currently taught, both procedures require that the suspect stands erect with feet together, hands at the sides, and head upright, facing forward.

However, there are numerous situations in which conducting the tests in the standing posture would be unsafe or impossible. The most common of these occurs when the suspect is significantly taller than the officer, such that the officer would not be able to see the standing suspect's eyes without seriously compromising the officer's safety. Adverse weather conditions can make testing at roadside dangerous for both the officer and the suspect. The suspect might be disabled or otherwise unable to stand upright as instructed. Stops at sobriety checkpoints may require the officer to make an initial assessment of a driver who is seated behind the wheel of the vehicle. Finally, the officer may be called to the scene of an accident in which the injured driver already is secured to a gurney or backboard by paramedics. In such cases, the officer must be sure the impairment and eye signs are not due to a medical emergency, such as head injury, stroke, or seizure, or to inappropriate, or inadvertent visual or vestibular stimulation, such as optokinetic nystagmus or positional nystagmus.

A recent study has demonstrated a high correlation of HGN results between standing and seated postures for low BACs.[13] The goals of the current study are to confirm the validity and reliability of the HGN and VGN tests in the standing posture and to establish their validity and reliability in the seated and supine postures for BACs up to and above the legal limit for all the United States and Canada.

Review of impaired eye movements

The eye movements of an impaired individual differ dramatically in appearance from those of a normal, sober individual and are easily observed by a trained officer, without the need for any specialized or sophisticated equipment. Fine-motor control of the eyes is characterized by the ability to make smooth-pursuit movements and to properly fixate stationary targets either straight ahead or to the side. Virtually all normal individuals can make smooth pursuit eye movements to track targets up to 30 deg/sec, and most can track targets at speeds up to 100 deg/sec.[14] If a target moves too quickly for the smooth pursuit system to track accurately, brief catch-up saccades will be interposed during the eye movement and the eyes will be seen to jerk as they follow the target. For impaired individuals, catch-up saccades are readily evident for target speeds of about 30 deg/sec. At high levels of impairment, an individual can even lose the ability to make saccades and, thus, will be able to follow a moving target only by moving the entire head and/or upper body.

Fixation of a stationary target involves the same neural centers in the brainstem and cerebellum as smooth pursuits, and may be thought of as a "zero-velocity" pursuit eye movement.[14] If fixation of a peripheral target cannot be maintained correctly, the eyes will drift back toward the center and jerk quickly toward the target. The drift toward the center represents the slow phase of the resulting nystagmus, while the jerk toward the target represents the fast phase. Thus, the direction of the fast phase will change with the direction of gaze.

Many normal, sober individuals initially will show one or two beats of small-amplitude nystagmus when the eyes are moved to extreme lateral gaze positions.[15] This is alternately termed *endpoint nystagmus* or *nystagmus at maximum deviation*. The nystagmus usually dissipates within 1

Table 1. Demographic data for the drinking volunteers in the study

		Female	Male
Age (yrs)	Number	37	59
	Mean (SD)	30.0 (8.4)	28.3 (8.1)
	Minimum	21.0	21.2
	Maximum	51.2	62.8
Weight (lbs)	Mean (SD)	150.2 (36.6)	198.0 (28.6)
	Minimum	100	148
	Maximum	270	283
Ethnicity	Asian	1	0
	African–American	0	2
	White	36	57
Prescription for driving	Spectacles	7	8
	Contact lenses	9	8
Pre-test	Equal pupil sizes	37	58
	Equal tracking	37	59

SD, Standard deviation.

to 2 seconds, if gaze is maintained at such a position. On the other hand, impaired individuals typically demonstrate distinct, large-amplitude nystagmus that is sustained for several seconds at these positions.[10,11]

Fatigue nystagmus will occur in normal, sober individuals when gaze is maintained at an extreme lateral position for 30 seconds or more.[15] A recent study suggests that lack of sleep may exaggerate normal endpoint nystagmus,[16] but no other studies are known to prove that sleeplessness or systemic fatigue affect any other eye movements.

Gaze-evoked, *gaze-induced*, or, simply *gaze nystagmus* is a sustained nystagmus prior to an extreme lateral gaze position. It is indicative of neurological damage if it occurs unilaterally or asymmetrically, and of alcohol and/or drug impairment if it is bilateral and somewhat symmetric.[17] In addition, high levels of alcohol impairment, or impairment with certain drugs, either alone or in combination with alcohol, may produce sustained, large-amplitude bilateral vertical nystagmus in upgaze but not downgaze.[17]

Alcohol will alter the viscosity of the endolymph in the vestibular apparatus. This will affect the individual's sense of balance and any eye movements that are influenced by the vestibular system.[18] Depending on the relative concentrations of alcohol in the blood and endolymph, *positional alcohol nystagmus* (PAN) may be induced in primary gaze when the head is tipped or tilted to a non-upright position. PAN originally was considered to be a very sensitive diagnostic assessment of alcohol intoxication.[19] This may be true in a clinical or laboratory setting, but it is not helpful to the officer in the field who does not have the testing equipment necessary to make the careful measurements. Nonetheless, officers must be aware that an unintentional head tilt by the subject may induce PAN, which may confound or exacerbate the other eye movements the officer is testing.

Methods

Alcohol workshops

Alcohol workshops are used to train recruits on the use of SFSTs and to re-acquaint officers who are training to become DREs with specifics of the SFSTs. Workshops usually last about 3 to 4 hours, during which subjects receive measured doses of alcoholic beverages for about 2 hours, as well as snack foods. Some subjects are purposely recruited as "placebo drinkers," maintaining zero or low BACs throughout the workshop. Each subject's BAC is carefully monitored throughout the workshop.

The current study was conducted at nine regularly scheduled workshops in Oregon, Washington, and Idaho. Evaluations were performed by experienced officers in a room or area separate from the training area, in order to avoid disrupting the trainees. Subjects were evaluated at four different times during each workshop. Baseline evaluations were performed at the beginning of the workshop, before the subject's first drink; BAC measurements confirmed that all subjects started with blood alcohol levels of 0.00%. The first set of evaluations was conducted about 1 hour after the start of drinking, the second set was conducted at the end of the 2-hour drinking period, and the final set was conducted at the end of the workshop, at least 1 hour after the last drink. Subjects did not consume any alcohol during the evaluations or BAC measurements. Subjects worked with the trainees as part of the regular workshop in the period between the second and final sets of evaluations.

Figure 1 Demonstration of Horizontal Gaze Nystagmus test in seated posture.

Subjects

Ninety-six volunteer drinkers—37 female and 59 male—participated in the study. Subjects were recruited from local colleges, military bases, prosecutors' and attorneys' offices, and police academy offices. Each subject signed an informed consent form.

Subjects were recruited solely on the basis of their availability, and not on their age, gender, weight, or ethnicity. Subject demographic data are summarized in Table 1. Table 1 also summarizes the types of prescription lenses used for driving, as well as equality of pupil sizes and ability to follow a stimulus (*see* Test Procedures) before the consumption of alcohol.

All subjects were of legal drinking age and acknowledged varying levels of experience with drinking alcohol. None of the subjects reported fatigue, presence of any health conditions, or use of any medications that precluded participation in the study. Three subjects at two workshops were unable to complete the testing; nonetheless, their data for the portions completed are included in the analyses we discuss here.

Evaluators

Forty law enforcement officers, all certified DREs and/or SFST instructors, volunteered as evaluators for the study. Officers had no other training duties or responsibilities during the workshops. Officers were recruited solely on the basis of their availability, and not on their experience or agency affiliation. Table 2 lists the officers, their agencies, and their relevant experience. Several officers, not indicated in Table 2, participated in more than one workshop each.

Each evaluator tested subjects only in one of three test postures (see later discussion). In order to mask evaluators from the results at the different postures, evaluators were discouraged from discussing their results during the workshop. Evaluators also were masked from the BAC measurements taken during the workshop.

Six evaluators were available at each workshop conducted in Washington and Idaho, and at two of the workshops in Oregon, evaluating a total of 25 female and 43 male subjects. Thus, each subject was tested separately by two evaluators at each posture at each test time. Three evaluators were available at each of the three remaining workshops in Oregon, evaluating a total of 12 female and 16 male subjects. These subjects were

Figure 2 Demonstration of Horizontal Gaze Nystagmus test in supine posture.

tested once at each posture at each test time. Combining data from all workshops, there was a maximum of 164 evaluations at each posture at each test time.

Test postures

Testing was conducted on each subject in three postures: standing, seated, and supine. The standing posture was consistent with that recommended by NHTSA guidelines and previous validation studies,[4,20-22] in that subjects stood with feet together, hands at the sides, and head upright, facing forward.

In the seated posture, the subject sat in an armless chair or folding chair, with head upright and turned approximately 45 degrees to the side. The evaluator stood to the same side as the subject's turned head, such that the subject always directly faced the evaluator (*see* Figure 1).

In the supine posture, subjects laid flat on their back atop stacked gym mats at a height of about 18 inches (46 cm). Subjects were instructed to keep their heads straight and in line with their bodies for all testing, except PAN (see below for clarification), and evaluators were instructed to perform the tests from directly above the subjects (*see* Figure 2).

BAC measurements

Blood alcohol levels were assessed at each test time during each workshop using calibrated breath analysis instruments and procedures equivalent to those required by each state for the assessment of an actual DUI suspect. Certified breath analysis specialists performed measurements using Intoxilyzer 5000 instruments in Oregon and Idaho, and DataMaster instruments in Washington. To establish BAC, Oregon requires only a single reading, whereas Idaho and Washington require two readings. All Idaho and Washington measurements reported here are the averages of the respective readings for each subject. The mean difference and standard deviation for all pairs of readings from Idaho and Washington are both 0.003%.

One subject at a Washington workshop, who did not complete the testing, was given a single measurement at the first and only evaluation time with a calibrated portable breath test instrument, so as to avoid possible contamination of the DataMaster instrument.

Table 2. Officers, listed alphabetically by state, who volunteered as evaluators for this study, including years of experience as certified Drug Recognition Experts (DREs) and/or Standardized Field Sobriety Test (SFST) instructors

State	Evaluator	Agency	DRE	SFST
Oregon	Deputy Scott Bressler	Benton County SO	3	9
	Officer David Driscoll	Salem PD	6	13
	Trooper Timothy Fox	SP	4	6
	Deputy Dustin Frenzel	Linn County SO	—	3
	Officer Robert Hayes	Albany PD	3	—
	Sergeant Lance Inman	Keizer PD	3	4
	Trooper Michael Iwai	SP	2	—
	Trooper Eric Judah	SP	3	—
	Officer Kristina Knox	Salem PD	5	4
	Officer David Leday	Keizer PD	4	3
	Officer Tim Lenihan*	Myrtle Creek PD	5	4
	Deputy Timothy McCall	Harney County SO	1	2
	Trooper David Peterson	SP	5	—
	Sergeant Robert Ruark	Polk County SO	1	<1
	Lieutenant Trace Schreiner	DPSST	3	4
	Officer Justin Stevenson	Dallas PD	1	1
	Officer K.T. Taylor	Sandy PD	—	2
	Sergeant Tim Weaver*	Newberg PD	2	2
	Trooper Steve Webster	SP	6	6
Washington	Trooper James Aye	SP	2	—
	Trooper Curt Boyle	SP	3	3
	Trooper Nathan Elias	SP	1	—
	Trooper Steve Gardner	SP	2	—
	Trooper Darrell Hash	SP	4	3
	Officer Michael Henry	Puyallup PD	4	3
	Trooper Harlan Jackson	SP	3	<1
	Officer Theresa Kubala	Vancouver PD	1	<1
	Trooper Bruce Lantz	SP	4	<1
	Trooper Darrin Latimer	SP	3	—
	Trooper Brian Mihelich	Sp	<1	—
	Trooper Shane Nelson	SP	1	—
	Trooper D.A. O'Neill	SP	4	1
	Officer Kelly Parsons	Walla Walla PD	3	<1
	Deputy J. Sousley	Pierce County SO	2	1
	Trooper Keith Trowbridge	SP	3	—
	Trooper David Wilbur	SP	3	3
Idaho	Corporal Craig Boll	SP	3	—
	Trooper T.J. Harms	SP	1	—
	Trooper Timothy Horn	SP	2	—
	Sergeant Timothy Johnson	SP	5	3
	Trooper Edward Robertson	Sp	2	—
	Corporal Lance Rogers	McCall PD	1	1

SP, State Police/Patrol; ***PD***, Police Department; ***SO***, Sheriff's Office/Department; and ***DPSST***, Department of Public Safety and Training.
* Participated in pilot study only.

Test procedures

Pre-test

At the start of the eye movement tests of the SFSTs, officers check for the presence of eyeglasses or contact lenses, and for ocular redness and excessive tearing.[4] They also assess the subject's pupil sizes and tracking ability. Previously undiagnosed anisocoria may indicate a recent head injury, such as trauma or stroke. Inability to follow the stimulus or non-congenital nystagmus—especially in primary gaze—also may indicate a head injury or the presence of drugs other than alcohol. The appearance of "bloodshot, watery eyes" may suggest recent exposure of the subject to a noxious environment, such as a smoke-filled room, but also occurs in response to the dehydrating effects of ingested alcohol.

Testing normally is not performed if the subject has congenital nystagmus, restricted eye movements (i.e., noted by the officer as "inability to follow the stimulus"), or blindness or loss of one eye. Otherwise, spectacles are removed during testing to allow the officer to see the subject's eyes when the stimulus is moved to lateral and upgaze positions. The officer confirms that the subject can see the stimulus—usually a pen, penlight, or fingertip—before starting the test. Soft or rigid contact lenses are kept in place, as they should not affect the testing. If they are properly fit and maintained, they should not be displaced or fall out during testing.

We have found that uncorrected high refractive error ($> \pm$ 8.00 D), astigmatism (0.50 and above at any axis), anisometropia (more than 1 D), amblyopia (two lines difference), and strabismus are not automatic disqualifiers for conducting the tests, since the stimulus does not have a high visual acuity demand, and since eye movements are not necessarily restricted with these conditions. Other pathological conditions, in the absence of medications that fall into any of the drug categories described earlier, do not produce eye movements that are similar to those observed with intoxication. For example, acquired nystagmus in vestibular diseases,[17] multiple sclerosis,[23] and a rare case of glaucoma[24] occur in primary gaze or with non-upright head positions. Likewise, changes in saccades and smooth pursuits with diabetes,[25] glaucoma,[26] multiple sclerosis,[27] and optic neuritis[27] will appear different than those assessed during the HGN test. Viral infections, such as cold and flu, will affect eye movements only if there is active involvement of the vestibular system or in the presence of impairing drugs.[28]

Horizontal gaze nystagmus (HGN)

Testing was conducted in the same manner in all test postures, consistent with NHTSA guidelines.[4,20] The stimulus was held in front of the subject's face, approximately 12 to 15 inches (30 to 38 cm) from the subject's nose and slightly above eye level. This elevated eye position raised the upper lids and allowed the evaluator a better view of the eyes, but did not affect the results of the test. The subject was instructed to keep his or her head still and follow the stimulus with the eyes only. The subject's left eye was observed first during each of the three component tests.

Smooth pursuit was assessed by moving the stimulus to extreme left gaze and then to extreme right gaze at about 30 deg/sec. The test was repeated at least once for each eye. Nystagmus at maximum deviation was assessed by moving the stimulus first to extreme left gaze, then to extreme right gaze, such that no temporal sclera showed at either position, and held at each position for at least 4 seconds. Onset of gaze nystagmus was assessed by moving the stimulus at about 15 deg/sec to each side until nystagmus was observed. If nystagmus was present, the evaluator determined whether the angle of onset was less than 45 degrees.

The HGN test is scored by the number of signs present for the two eyes, scoring one sign each per eye for lack of smooth pursuit, sustained nystagmus at maximum deviation, and onset of gaze nystagmus prior to 45 degrees. Therefore, the maximum number of signs is six. Previous laboratory and field validation studies have consistently demonstrated that the presence of four or more signs is highly correlated with BAC at either 0.10%[10,11] or 0.08%.[21,22,29]

Vertical gaze nystagmus (VGN)

Testing was conducted in the same manner in all test postures, consistent with NHTSA guidelines.[4,20] The stimulus was held in front of the subject's face, approximately 12 to 15 inches (30 to 38 cm) from the subject's nose. The subject was instructed to keep his or her head still and follow the stimulus with eyes only. The stimulus was raised until the subject's eyes were in extreme upgaze, and held at that position for approximately 4 seconds. Sustained vertical nystagmus indicated a positive result.

Positional alcohol nystagmus (PAN)

Officers normally do not assess PAN, but it is mentioned in the training manual as a type of nystagmus of which they must be aware.[4] PAN may be induced in an alcohol-impaired individual when the head is tilted with respect to straight ahead, with the nystagmus present in primary gaze. Previous research has demonstrated that PAN is not induced in a supine posture, when the head is in line with the body.[18] The presence of PAN is easily differentiated from the types of nystagmus expected during the HGN and VGN tests due to the non-upright head position and straight-ahead gaze.

In this study, in the standing and seated postures, the presence of PAN was assessed by having the subject tilt the head toward either shoulder (*see* Figure 3, *A*). In the supine posture, the subject turned the head to the side toward the evaluator (*see* Figure 3, *B*). In all test postures, the subject maintained fixation on the stimulus held approximately 12 to 15 inches (30 to 38 cm) from the nose. Nystagmus in primary gaze indicated a positive result.

Figure 3 Demonstration of test for Positional Alcohol Nystagmus (PAN) in ***A***, standing and ***B***, supine postures. Test for PAN in seated posture (not shown) incorporates head tilt identical to that in standing posture.

Results

Demographic data

The average age of all subjects was 29.0 years; ranging from 21 to 62 years (*see* Table 1). There was no significant difference in subject ages based on gender ($p = 0.351$). There was a significant difference in subject weights based on gender ($p = 0$), with males consistently heavier than females.

The high percentage of white subjects (97%) reflects the population of the Pacific Northwest. Follow-up studies with more ethnically diverse populations are encouraged. Thirty-two subjects (33%) wore or reported the need to wear either spectacles or contact lenses for driving. Lens prescriptions were not considered in this study, as the only criterion was the ability of the subject to see and follow the stimulus used by the evaluator; no subjects had difficulty with these tasks under the given conditions. Anisocoria was noted in a single subject in Oregon. The condition was determined to be longstanding, the subject was aware of it, and it did not affect testing in any way. All subsequent results are reported without regard to gender, weight, ethnicity, or type of ophthalmic prescription.

Blood alcohol levels

BAC measurements were taken toward the end or after each set of evaluations, on average between 4.5 and 23.5 minutes from the midpoint of any given set of evaluations. The longest time

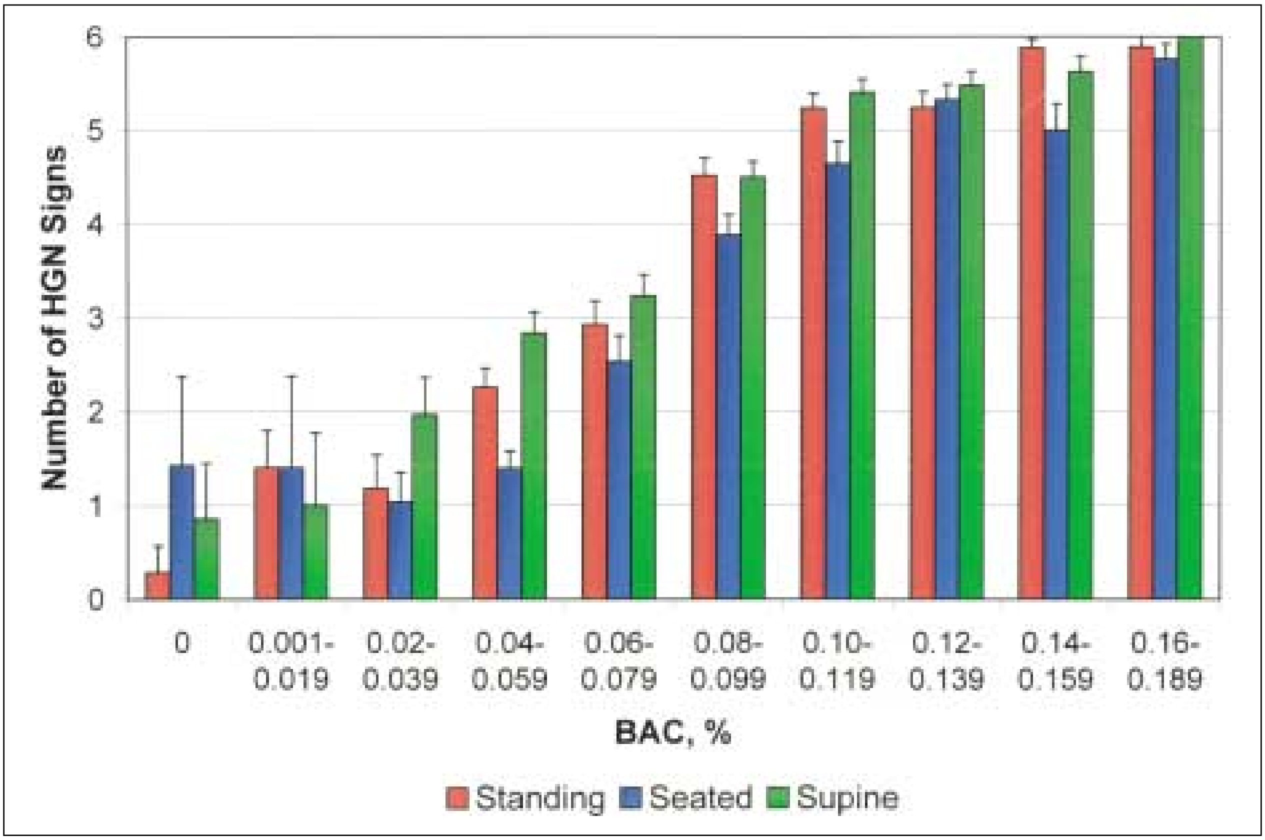

Figure 4 For each test posture and BAC range, average number of HGN signs observed at each BAC range, with standard error bars.

difference for an individual subject was about 50 minutes. Since the typical elimination rate of alcohol is about 0.015% per hour for an average adult,[30] the measurements provide an accurate assessment of the BACs of the subjects during each set of evaluations.

Of the 284 total measures, 156 (54.9%) were at 0.08% and higher; 95 of all measures (33.5%) were at 0.10% and higher. The highest individual BACs were 0.189% for a subject in Washington, 0.179% for an Idaho subject, and 0.176% for an Oregon subject.

HGN

Because of variations in physiology and neurology in otherwise normal, sober subjects, an officer may observe individual signs during HGN testing that appear similar to the signs observed when the subject is impaired.[6] Nonetheless, the overall number and pattern of signs observed in a sober subject will be different than those seen in an impaired subject. Also, as borne out by the results of this study, signs typically appear in the order of performance of the HGN test, and symmetrically in the two eyes, with increasing levels of impairment.

Baseline evaluations of sober subjects

Of the 164 evaluations conducted at each test posture at baseline, fewer than 10% at any posture demonstrated (at most) three HGN signs. There are no significant differences based on test posture for lack of smooth pursuit, sustained nystagmus at maximum deviation, and onset of gaze nystagmus prior to 45 degrees (all $p > 0.09$).

Only one evaluator observed four signs (endpoint nystagmus in both eyes and gaze nystagmus prior to 45 degrees in both eyes) on a single subject in the standing posture, but these signs were not observed by evaluators in the seated and supine postures. At no posture during the baseline evaluations were five or six signs observed on any subject. There is no significant difference based on test posture for the number of HGN signs observed ($p = 0.518$).

Table 3. Sensitivity, false alarm rate, accuracy, and detectability index for HGN data at each test posture at two criterion blood alcohol concentration (0.08% and 0.10%)*

	Posture			
BAC = 0.08%	Standing	Seated	Supine	McKnight et al.
Sensitivity	0.890	0.799	0.891	0.75
False alarm rate	0.367	0.285	0.462	0.32
Accuracy	77.3%	76.1%	73.0%	71%
d'	1.568	1.407	1.326	1.15
BAC = 0.10%	Standing	Seated	Supine	Good and Augsburger
Sensitivity	0.956	0.887	0.969	0.96
False alarm rate	0.503	0.408	0.561	0.82
Accuracy	64.7%	68.9%	61.3%	90%
d'	1.698	1.442	1.708	0.88

d', Detectability index; ***HGN***, horizontal gaze nystagmus; and ***BAC***, blood alcohol concentration.

* Included for comparison are calculations based on the data recorded by McKnight et al.,29 testing in a seated posture, and Good and Augsburger, 5 testing in a standing posture.

Test evaluations—Analysis by BAC

Figure 4 shows the average number of HGN signs, and standard error of the mean, at each test posture and range of BACs. Note that all but the last of the non-zero BAC ranges are in increments of 0.02%; only one subject achieved a blood alcohol level above 0.18% for a single measurement.

Chi-square analysis shows that there is a statistically significant difference in the number of HGN signs observed based on test posture, $\chi^2(12) = 45.49$; $p = 0$. Compared to the standing posture, evaluators typically observed fewer signs in the seated posture and more signs in the supine posture. However, for subjects with BACs above 0.06%, the greatest difference in the mean number of signs observed at the different test postures is less than one. Thus, while the differences may be statistically significant, they are not of practical significance for the officer in the field. Note that, on average, evaluators consistently observed more than four signs for BACs of 0.10% and higher, and about four signs for BACs between 0.08 and 0.10%.

The relationship between each subject's BAC and the number of HGN signs observed by each evaluator is given by the correlation coefficient. The coefficients for the current study are all very high and statistically significant at $p = 0$: for the standing posture, $r = 0.63$; for the seated posture, $r = 0.59$; and for the supine posture, $r = 0.59$. By comparison, Stuster and Burns[22] reported a correlation coefficient of 0.65 between BAC and HGN tested in the standing posture, while McKnight et al.[29] reported correlations of 0.56 and 0.55 for the standing and seated postures, respectively. The correlations of the current study are not significantly different from those reported by either Stuster and Burns or McKnight et al. (all $p > 0.13$).

Nonetheless, the purpose of a sobriety test is not to estimate an individual's BAC, but to determine if that individual is impaired: if the impairment is due solely to alcohol intoxication, the sobriety test can discriminate whether the individual is over or under the legal limit for BAC.[10] Signal detection theory provides several measures that describe the ability of a test to discriminate at a given criterion level.[31] *Sensitivity*, also known as the true positive ratio, is the proportion of subjects who show a positive test result to all subjects who actually have the given condition. The *false alarm rate* is the proportion of subjects who show a positive test result to all subjects who do not have the given condition. *Accuracy* is the percentage of subjects correctly identified as having the condition and not having the condition. An ideal test will have sensitivity equal to one, false alarm rate of zero, and accuracy of 100%. The *detectability index, d'*, is a measure of the ability of the test to discriminate signal from noise, or—in the present context—to determine if a test can discriminate a finding from a random or chance result.[32]

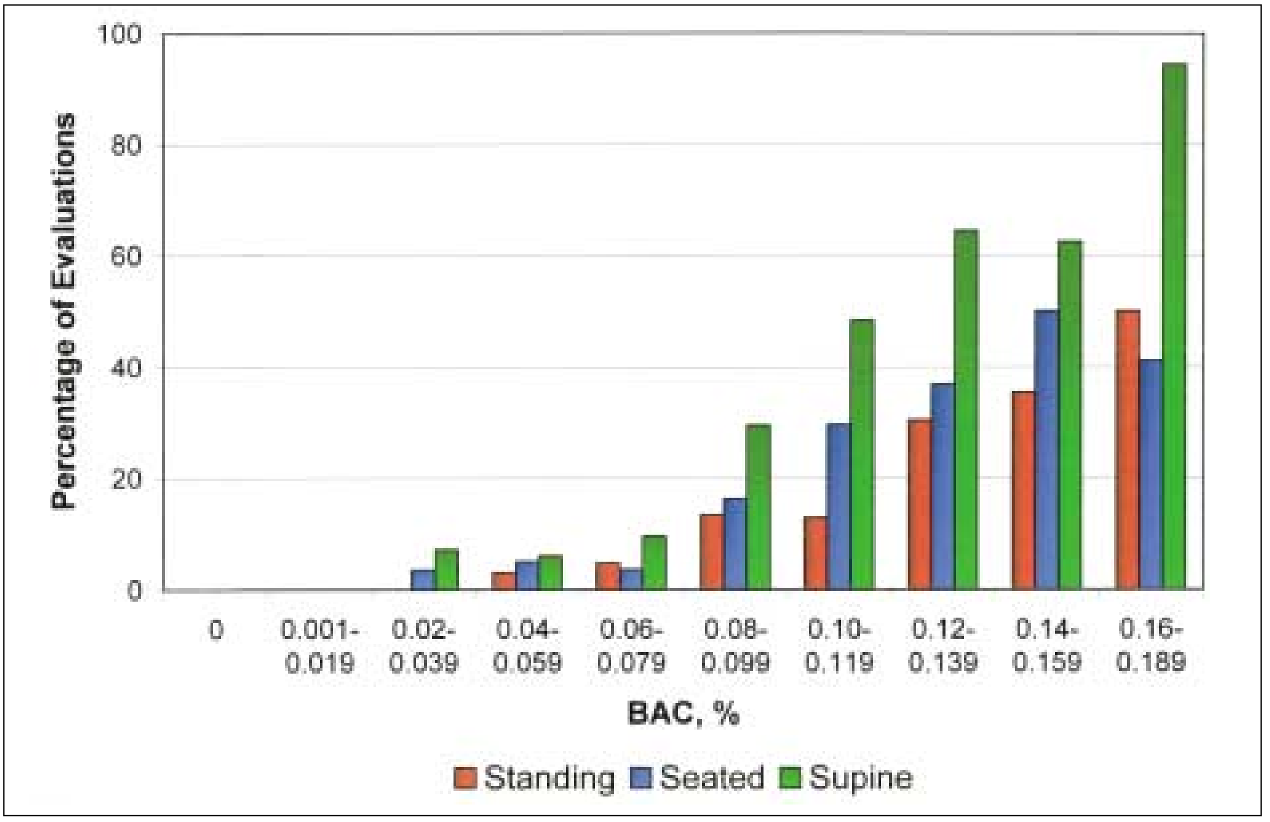

Figure 5 Percentage of evaluations at each test posture in which VGN was observed for the given BAC ranges.

Table 4. Inter-posture reliabilities, test–retest reliabilities, and test–retest accuracy for the HGN test conducted at different postures and by pairs of evaluators*

	Reliability			Accuracy
Posture:	Seated	Supine	Test–retest	Test–retest
Standing	0.672	0.616	0.589	76.1%
Seated	—	0.638	0.653	73.1%
Supine	—	—	0.713	84.7%

HGN, Horizontal gaze nystagmus.
* All reliabilities are significant at p = 0.

Sensitivity, false alarm rate, accuracy, and *d'* of the HGN test at each test posture for each of two criterion BACs, 0.08% and 0.10%, are shown in Table 3. Sensitivity and accuracy are consistently very good for all measures, and false alarm rates are acceptable, given the fact that the result of the HGN test provides only one of many possible pieces of evidence of impairment to an officer.[4] All *d*'s are significant at $p = 0$, indicating that the evaluators could correctly discriminate impairment at all postures for either criterion BAC. Table 3 also shows comparable results for Good and Augsburger[5] and McKnight et al.[29] Note that Good and Augsburger used a criterion BAC of 0.10%, which was the legal limit in Ohio at the time of that study, with HGN conducted in the standing posture. In contrast, McKnight et al. used a criterion BAC of 0.08%, with HGN conducted in a seated posture.

Inter-posture and inter-evaluator reliability

Separate evaluators conducted testing at the different postures. In addition, most tests were conducted by two evaluators at each posture, allowing an assessment of *test–retest reliability*.

Table 5. Sensitivity, false alarm rate, accuracy, and detectability index for VGN data at each test posture at two criterion blood alcohol concentrations (0.08% and 0.10%)*

	Posture		
BAC = 0.08%	Standing	Seated	Supine
Sensitivity	0.215	0.289	0.485
False alarm rate	0.032	0.041	0.072
Accuracy	0.560	0.594	0.687
d'	1.066	1.184	1.420
BAC = 0.10%	Standing	Seated	Supine
Sensitivity	0.268	0.371	0.610
False alarm rate	0.065	0.080	0.144
Accuracy	0.718	0.739	0.775
d'	1.897	1.074	1.341

d', Detectability index; ***VGN***, vertical gaze nystagmus; and ***BAC***, blood alcohol concentration.

Table 6. Inter-posture reliabilities, test–retest reliabilities, and test–retest accuracy for the VGN test conducted at different postures and by pairs of evaluators*

	Reliability			Accuracy
Posture:	Seated	Supine	Test–retest	Test–retest
Standing	0.324	0.357	0.369	85.4%
Seated	—	0.391	0.401	83.0%
Supine	—	—	0.515	79.7%

VGN, Vertical gaze nystagmus.
* All reliabilities are significant at p = 0.

The reliability of the HGN test, both between different postures and for test–retest, is given by the correlation coefficient. For psychomotor tests, such as HGN, a highly reliable test has a correlation coefficient of about 0.7.[33] Test–retest accuracy is a measure of the consistency between evaluators.

Table 4 shows the inter-posture and test–retest reliabilities, as well as the test–retest accuracies for the current study. By comparison, the HGN test conducted in the standing posture previously has been shown to have test–retest reliability of 0.59:[11] this is not significantly different from any of the test–retest reliabilities for the current study (all $p > 0.40$). On the other hand, McKnight et al.[13] reported a correlation of 0.94 between the results of the standing and seated postures. This is very likely due to the fact that the same evaluator tested each subject in both postures in that study, whereas the current study used different evaluators for each posture.

For all test postures, there is no correlation between evaluator experience and the number of HGN signs observed. All correlation coefficients are close to zero ($|r| < 0.15$), and not significant (all $p > 0.05$).

VGN

VGN is not expected in normal, sober subjects in the absence of neurological problems. With the use of alcohol alone, VGN may not appear until a high level of impairment is achieved, as defined for the individual subject.[4] VGN may be present when other CNS-depressant drugs, inhalants, or PCP are used, either separately or in combination, or with alcohol.

Baseline evaluations of sober subjects

Of the 164 evaluations conducted at each test posture at baseline, VGN was observed on only a single subject by one evaluator in the supine posture. However, VGN was not observed on the same subject by the same evaluator at the first evalu-

Table 7. Number of evaluations at each test posture in which HGN and VGN were observed*

HGN observed?	VGN observed?	Posture		
		Standing	Seated	Supine
Yes	Yes	62	79	144
Yes	No	251	194	193
No	Yes	1	6	0

HGN, Horizontal gaze nystagmus and ***VGN***, vertical gaze nystagmus.
* Presence of HGN is determined by the observation of at least four signs during testing.

ation, when the subject had a blood alcohol level of 0.02%. It also was not observed by any other evaluator in any other test posture either at baseline or the first evaluation.

Test evaluations—Analysis by BAC

Figure 5 shows the percentage of evaluations at which VGN was observed at each test posture for the given BAC ranges. Chi-square analysis shows that there is a statistically significant difference in the observation of VGN based on test posture, $\chi^2(2) = 44.43$; $p = 0$. Compared to the standing posture, VGN typically was observed more frequently in the seated and supine postures.

However, the differences based on test posture are only evident for BACs at 0.08% and higher. Of the 221 evaluations conducted at each test posture on subjects with BACs below 0.08%, VGN was observed only on seven subjects (3.2%) in the standing posture, nine subjects (4.1%) in the seated posture, and 16 subjects (7.2%) in the supine posture. These findings do not differ significantly ($p = 0.112$). On the other hand, for subjects with BACs of 0.08% and higher, VGN was observed in 21.5% of evaluations in the standing posture, 28.9% in the seated posture, and 48.5% in the supine posture. At BACs of 0.10% and higher, the percentages of observations at each posture were 26.8%, 37.1%, and 61.0%, respectively.

The correlation coefficients, relating each subject's BAC to the observation of VGN by each evaluator, are all good and statistically significant (all $p = 0$): for the standing posture, $r = 0.35$; for the seated posture, $r = 0.37$; and for the supine posture, $r = 0.52$.

Sensitivity, false alarm rate, accuracy, and *d'* of the VGN test at each test posture for each of two criterion BACs, 0.08% and 0.10%, are shown in Table 5. All d's are significant at $p = 0$. While the sensitivities are all relatively low, the false alarm rates are excellent, and the accuracies are very good.

Inter-posture and inter-evaluator reliability

Reliabilities between test postures and pairs of evaluators, and test–retest accuracies, were determined as for the HGN test discussed earlier. Table 6 shows the inter-posture and test–retest reliabilities, as well as the test–retest accuracies for the VGN test.

For all test postures, there is no correlation between evaluator experience and the observation of VGN. All correlation coefficients are close to zero ($|r| < 0.09$), and not significant (all $p > 0.05$).

Combined results of HGN and VGN tests

Table 7 shows the number of evaluations at each test posture in which HGN and VGN were observed. Presence of HGN is determined by the observation of at least four signs during testing. The data are consistent with the fact that when impairment is due to alcohol and/or drugs, VGN will be present only when HGN is present.[4] For the single evaluation in the standing posture in which VGN was observed and HGN was not, the evaluator did note two signs of HGN and the subject's BAC was 0.09%. All six evaluations in the seated posture, in which VGN was observed and HGN was not, were conducted by the same evaluator. The evaluator noted either two or three HGN signs for each evaluation, and three of these subjects had BACs above 0.08%. Thus, the observation of VGN alone would have correctly identified four of the seven subjects as above the 0.08% limit for BAC. In all seven cases, it is most likely that the evaluators experienced difficulty observing the subjects' eyes, but the data demonstrate that this was not a widespread or overwhelming problem for the study.

PAN

Results are presented to demonstrate that officers can correctly identify and distinguish PAN from other types of nystagmus. It is not the intention of this study to include the observation of PAN during an actual DUI or DRE evaluation. Thus, it is of little value to report sensitivity analysis values or reliabilities. For the interested reader, those values are very similar to those reported for the VGN test discussed earlier.

Baseline evaluations of sober subjects

Of the 164 evaluations conducted at each test posture at baseline, PAN was observed on only two subjects at one workshop by the same evaluator in the standing posture. However, PAN was not observed on the same subjects by any of the other five evaluators.

Test evaluations—Analysis by BAC

Chi-square analysis shows that there is a statistically significant difference in the observation of PAN based on test posture, $\chi^2(2) = 41.80$; $p = 0$. PAN was observed with approximately equal frequency in the standing and seated postures, but with greater frequency in the supine posture. Nonetheless, PAN was observed in fewer than 10% of all evaluations with BAC below 0.08%. In addition, because of the head tilt required to induce PAN, it should never be mistaken as a sign of HGN or VGN.

Discussion

Consistent with previously published results, we confirm the validity of the HGN test in the standing posture to discriminate blood alcohol levels of 0.08% and 0.10%. We also establish, with similar accuracies and reliabilities, the use of the HGN test in the seated and supine postures. The average inter-evaluator reliability and accuracy demonstrate that HGN is a highly reliable test.

However, there were statistically significant differences in the observation of HGN based on test posture. We attribute these differences to the ability of the evaluator to detect the signs, rather than to incorrectly identify PAN as a sign of HGN. Evaluators conducting the test in the seated posture occasionally reported difficulty seeing the subject's eye that was opposite the head turn. On the other hand, evaluators conducting the test in the supine posture could easily shift position either along or across the subject's body to better observe the eyes during each part of the test.

Nonetheless, these differences do not suggest that impaired seated subjects would be mistaken as sober, nor that sober supine subjects would be mistaken as impaired. As shown in Figure 4, evaluators typically observed fewer than two signs on subjects with BACs below 0.04%, and four or more signs on subjects with BACs at 0.10% and higher, regardless of posture. For subjects with BACs between 0.08% and 0.10%, evaluators observed (on average) about 4.5 signs in the standing and supine postures and 3.9 signs in the seated posture. While statistically significant, these differences are not of practical significance to the officer in the field.

We recommend that the officer who needs to conduct the HGN test in the seated posture position the subject in such a way that the subject's eyes can be seen easily throughout the test. This may involve asking the subject to turn the body slightly at the waist, in addition to the head turn used in the current study. Such a minor change in posture will not affect the results.

We also confirm that VGN is present only when signs of HGN are present, and that the VGN test can be used to identify high levels of impairment at any test posture. Again, we attribute the statistical difference in observation of VGN at the different postures to the ease with which the evaluators could detect the nystagmus, rather than the influence of the postures themselves. As shown in Figure 5, fewer than 10% of subjects with BACs below 0.08% exhibited VGN at any posture, whereas at least 30% of subjects with BAC at and above 0.12% exhibited VGN.

Conclusion

Officers in the field observe various indicators of a driver's impairment, including driving behavior, physical signs, and performance on psychophysical tests. We conclude that the proper use of the HGN and VGN tests at any test posture will help an officer correctly identify individuals impaired with alcohol at BACs of 0.08% and higher. By extension, since other CNS depressant drugs, inhalants, and PCP affect the same neural centers as alcohol, DRE officers can use the same tests and test postures to aid in identification of impairment with substances other than, or in addition to, alcohol.

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Corresponding author:

Karl Citek, O.D., Ph.D.
Pacific University
College of Optometry
2043 College Way
Forest Grove, Oregon 97116

citekk1@pacificu.edu