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Nystagmus & convergence testing in intoxicated individuals

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Abstract

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 assessments of eye movements, using the Horizontal Gaze Nystagmus (HGN), and Vertical Gaze Nystagmus (VGN) tests, which are conducted at roadside by patrol officers. Law enforcement officers trained as Drug Recognition Experts (DREY's) use the HGN and VGN test along with an additional test to assess drug impairment known as the Lack of Convergence (LOC) test. LOC will be present with intoxication due to certain drugs other than, or in addition to, alcohol. The HGN and VGN tests previously also have only been validated when the subject is placed in a standing posture with head upright. The LOC test previously has been validated in the same posture with head upright, but with a high number of false positives. However, certain conditions require that the subject be tested while seated or supine. The goals of the current study are to confirm the validity and reliability of HGN and VGN in the standing posture and to establish their validity and reliability in the seated and supine postures. It is also a goal to determine a criterion distance that reduces the number of false positives, and to establish the validity and reliability of the LOC test for standing, seated and supine postures.

Methods. The study was conducted at 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 clues observed during the HGN test at any posture increase with increasing BAC. The presence of VGN at any test posture occurs only at high levels of intoxication, as defined for the individual subject. The presence of LOC at any test posture increases with increasing BAC. A criterion distance of 3 in (8 cm) from the bridge of the nose reduces the number of false positives observed.

Conclusions. The HGN test administered in t'he standing, seated, and supine postures is able to discriminate intoxication at criterion BAC's of 0.08 and 0.10%. The HGN test also is able to discriminate intoxication at BAC's below 0.08%. The VGN test is able to identify high levels of intoxication at any test posture. Therefore, these tests can be used by an officer to determine if a driver is intoxicated regardless of whether the driver is standing, seated, or supine. With the new criterion distance, the LOC test administered in the standing, seated, and supine postures aids in the discrimination of intoxication at criterion BAC9s of 0.08 and 0.10%, as well as at BAC's below 0.08%. The LOC test should, therefore, be able to aid in the detection of intoxication due to drugs other than alcohol that have similar effects on convergence. This test can be used by a DRE to determine if a driver is intoxicated regardless of whether the driver is standing, seated, or supine.

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NYSTAGMUS & CONVERGENCE TESTING IN INTOXICATED INDIVIDUALS

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Biographies

BRET BALL. A native of Idaho Bret grew up on a small farm in Rigby Idaho. He attended Ricks College in Rexburg, Idaho for a year and a half studying business and then transferred to Idaho State University in Pocatello, Idaho. There he graduated with honors earning a Bachelors of Science in Biology. He is currently attending Pacific University College of Optometry as a fourth year honor student and a member of BSK. Upon completion of his Doctor of Optometry degree he plans to enter private practice and pursue a clinical career in optometry.

ABSTRACT

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 assessments of eye movements, using the Horizontal Gaze Nystagmus (HGN), and Vertical Gaze Nystagmus (VGN) tests, which are conducted at roadside by patrol officers. Law enforcement officers trained as Drug Recognition Experts (DRE's) use the HGN and VGN test along with an additional test to assess drug impairment known as the Lack of Convergence (LOC) test. LOC will be present with intoxication due to certain drugs other than, or in addition to, alcohol. The HGN and VGN tests previously also have only been validated when the subject is placed in a standing posture with head upright. The LOC test previously has been validated in the same posture with head upright, but with a high number of false positives. However, certain conditions require that the subject be tested while seated or supine. The goals of the current study are to confirm the validity and reliability of HGN and VGN in the standing posture and to establish their validity and reliability in the seated and supine postures. It is also a goal to determine a criterion distance that reduces the number of false positives, and to establish the validity and reliability of the LOC test for standing, seated and supine postures.

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Key Words: law enforcement, alcohol, intoxication, blood alcohol concentration, smooth pursuit, endpoint nystagmus, gaze nystagmus, vertical nystagmus, positional alcohol nystagmus, convergence, lack of convergence, nearpoint of convergence, BAC, HGN, VGN, PAN, BAC, LOC, NPC.

INTRODUCTION

In the United States, drivers impaired by alcohol and/or drugs annually are responsible for over 16,000 deaths, one million injuries, and $45 billion in costs.' As part of the attempt to reduce these human and economic tolls, law enforcement officers routinely conduct several eye movement tests to determine if a driver is under the influence of alcohol, other central nervous system (CNS) depressant drugs, inhalants, or phencyclidine (PCP) and its analogs. In addition, certain antihistamines have physiologic and cognitive effects similar to CNS depressant drugs. All of these substances will affect, to various extents, the neural centers in the brainstem and cerebellum controlling eye movements, as well as other motor, sensory, and cognitive integration areas of the brain. Alcohol also will alter the viscosity of the endolymph in the vestibular apparatus, which will affect an intoxicated individual's sense of balance and any eye movements that are influenced by the vestibular system.

The eye movements of an intoxicated individual differ dramatically in appearance from those of a normal, sober individual and are easily recognized by a trained officer without the need for any specialized or sophisticated equipment. Loss of fine motor control of eye movements with alcohol intoxication, as demonstrated with the Horizontal Gaze Nystagmus (HGN) test, has been shown to correlate highly with cognitive impairment.[2] Therefore, an officer who properly conducts HGN and other testing, described below, and who observes eye movement signs, or clues, consistent with intoxication, may arrest a driver and request a sample for chemical analysis from him/her in order to objectively assess the blood alcohol concentration.

Specially trained law enforcement officers are taught to recognize indicators in drivers that are consistent with intoxication due to drugs other than, or in addition to, alcohol.[3] These officers are known as Drug Recognition Experts (DRE's), and the training program and techniques are currently in use in 33 states, the District of Columbia, and several foreign countries. Based on the observation of various physiological signs and psychomotor tests, the DRE can accurately determine if the impairment is due to drug intoxication, and, if so, the type of drug or drugs that have been used.[4-6]

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, and commonly reported as a percentage of alcohol weight per volume of blood. When impairment is due solely to alcohol intoxication, 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%. On the other hand, commercial bus and truck drivers have a national limit of only 0.04%, which is more consistent with the statement by the American Medical Association recognizing that driver impairment is evident at 0.05%.[7] Many nations have set the legal limit at 0.05%, with Russia and Sweden reducing it to 0.02% and Japan going so far as to reduce it to 0.00%.[8] Many jurisdictions in the U.S. with zero-tolerance ordinances require stiff penalties and loss of driving privileges for underage drinkers demonstrating any non-zero BAC.

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 about 30 deg/sec, and many can track targets at speeds up to 100 deg/sec.[9] However, if a target moves too quickly for an individual's 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 intoxicated individuals, catch-up saccades are readily evident for target speeds equal to or less than 30 deglsec; this is termed "lack of smooth pursuit." At high levels of intoxication, an individual can even lose the ability to make saccades and, thus, only will be able to follow a moving target by moving the entire head and/or upper body.

Fixation of a stationary target involves the same neural centers as smooth pursuits, and may be thought of as a "zero-velocity" pursuit eye movement.[9] 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 individuals show one or two beats of small-amplitude nystagmus when the eyes are maintained at extreme lateral gaze positions,[10] whereas intoxicated individuals typically demonstrate sustained, large-amplitude nystagmus at these positions. This is alternately termed "endpoint nystagmus" or "nystagmus at maximum deviation."

Presence of sustained nystagmus prior to an extreme lateral gaze position is indicative of neurological damage if it occurs unilaterally or asymmetrically, and of intoxication if it is bilateral and somewhat symmetric.[10] In addition, high levels of alcohol intoxication, or intoxication with certain drugs, either alone or in combination with alcohol, may produce sustained, large-amplitude bilateral vertical nystagmus in up-gaze but not down-gaze.[11]

Positional alcohol nystagmus (PAN) may be present due to the altered output of the vestibular system with alcohol intoxication.[12] PAN is seen during straight-ahead fixation when the head is tipped or tilted to a non-upright position.

The HGN test assesses lack of smooth pursuit, sustained endpoint nystagmus, and presence of lateral gaze nystagmus prior to a gaze angle of 45 deg, and the Vertical Gaze Nystagmus (VGN) test assesses nystagmus induced in up-gaze. The HGN test is used by officers at roadside as part of the Standardized Field Sobriety Tests (SFST's).[13-15] Recently, the VGN test has been added as part of the SFST training for patrol officers.[13] The tests 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 at the police station 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.[3] Results of these tests, along with those of other tests and observations, allow the officer to accurately and reliably detect the presence of CNS depressant drugs, inhalants, and PCP.[16,17]

The procedure of the HGN test was standardized over 20 years ago by the National Highway Traffic Safety Administration (NHTSA).[18,19] In the mid 1980's, NHTSA standardized the procedure of the VGN test as part of the DRE evaluation.[20] Both procedures require that the subject stands erect with feet together, hands at the sides, and head upright and 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 is with a subject who is significantly taller than the officer; in the standing posture, the officer would not be able to see the subject's eyes or even conduct the test without seriously compromising the officer's safety. Adverse weather conditions can make testing at roadside dangerous and unsafe, or the subject might be handicapped or otherwise unable to stand upright as instructed. Likewise, 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, or the officer may be called to the scene of an accident where the injured driver already is secured in a gurney or backboard by paramedics. In all cases, the officer must be sure that 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, as with optokinetic nystagmus or PAN.

Prohibitions against unreasonable search and seizure prevent an officer from detaining a driver for an indefinite period, requesting a sample for chemical analysis without probable cause, or asking a driver who is not under arrest to return to the station for further testing. Proper use of the HGN and VGN tests will help an officer to make a fairly rapid decision regarding whether to arrest the driver on a DUI charge, refer the driver for immediate medical care, or send the driver safely on his/her way.

The American Optometric Association has previously recognized the validity and reliability of the HGN test as used by the law enforcement community.[21]

Vergence ability also is affected by alcohol intoxication.[22] The effects most readily seen results in changes in nearpoint convergence (NPC). Most normal, sober individuals should be able to converge the eyes to within about 4 in (10 cm) from the eyes, measured with respect to the ocular centers of rotation.[23,24] However, prevalence data for binocular vision problems in adults are not readily available. We can infer from the data for 6- to 18-year-olds[25] that about 10 to 15% of an otherwise normal adult population have a binocular vision problem, such as convergence insufficiency, intermittent strabismus, and small-angle strabismus, that would preclude a NPC of 4 in (10 cm) or less. Also, convergence insufficiency seems to increase with age, as subjects become presbyopic.[26]

With intoxication, the vergence system will tend to go to its resting level, typically just beyond arm's-length, and the individual will find it difficult both to diverge and converge the eyes with respect to that resting position.[22] Hence, many intoxicated individuals will report diplopia when viewing at both far and near distances. Previous studies have demonstrated that

NPC recedes with intoxication.[27-29] However, these studies were conducted on limited numbers of subjects using laboratory procedures and instruments different than those commonly used by law enforcement officers. In addition, two of the studies[28-29] did not directly measure blood alcohol concentration (BAC), but only estimated BAC based on each subject's weight and the amount of alcohol consumed.

As conducted by the DRE, the Lack of Convergence (LOC) test assesses the ability to converge the eyes to the bridge of the nose.[30] However, even in the absence of any frank binocular vision problems, many sober subjects cannot converge their eyes by this amount, resulting in a high number of false positives. In addition, the LOC test has been validated as part of the DRE procedure only when the subject is standing.[4] There are occasions, described previously, when the DRE must perform the test with the subject seated or supine.

The goals of the current study are to determine a criterion distance for the LOC test that reduces the number of false positives, and to establish the validity and reliability of the test for the standing and non-standing postures.

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METHODS

Alcohol Workshops

Alcohol workshops are used to train recruits on the use of SFST's and to re-acquaint officers who are training to become DRE's with specifics of the SFST's. Workshops usually last about three to four hours, during which subjects receive measured doses of their alcoholic beverages of choice for about two hours, as well as snack foods. Some subjects are purposely recruited as "placebo drinkers," maintaining zero or low BAC's 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 for this study were performed by experienced officers in a room or area separate from the training area in order to avoid disrupting the trainees. Each subject was evaluated at four times during each workshop. Baseline evaluations were performed at the beginning of the workshop, prior to 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 one hour after the start of drinking, the second set was conducted at the end of the two-hour drinking period, and the final set was conducted at the end of the workshop, at least one hour after the last drink. Subjects did not consume any alcohol while they were being evaluated. Subjects worked with the trainees as part of the regular workshop in the period between the second and final sets of evaluations.

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 based solely on their availability, and not on their age, gender, weight, or ethnicity. These 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 below) prior to the consumption of alcohol.

Table 1. Demographic data for the drinking volunteers in the study. s.d. = standard deviation.

		Female	Male
Age, yrs	Number	37	59
	Mean (s.d.)	30.0 (8.4)	28.3 (8.1)
	Minimum	21.0	21.2
	Maximum	51.2	62.8
Weight, lbs	Mean (s.d.)	150.2 (36.6)	198.0 (28.6)
	Minimum	100	148
	Maximum	270	283
Ethnicity	Asian	1	0
	African-American	0	2
	Caucasian	36	57
Prescription for Driving	Spectacles	7	8
	Contact Lenses	9	8
Pre-Test	Equal Pupil Sizes	37	58
	Equal Tracking	37	59

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 below.

Evaluators

Forty law enforcement officers, all certified DRE's and/or SFST instructors, volunteered as evaluators for the study, Officers had no other training duties or responsibilities during the workshops. Officers were recruited based solely on 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 below). 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. Each of these subjects was tested once at each posture at each test time. Combining data from all workshops, there were a maximum of 164 evaluations at each posture at each test time.

Table 2. Officers, listed alphabetically by state, who volunteered as evaluators for this study, including the year certified as a Drug Recognition Expert (DRE) and/or Standardized Field Sobriety Test (SFST) Instructor. SP = State Police/Patrol; PD = Police Department; SO = Sheriffs Office/Department; DPSST = Department of Public Safety Standards and Training. *Participated in pilot study only.

State	Evaluator	Agency	DRE	SFST
Oregon	Deputy Scott Bressler	Benton County SO	1998	1992
	Officer David Driscoll	Salem PD	1995	1988
	Trooper Timothy Fox	SP	1997	1995
	Deputy Dustin Frenzel	Linn County SO		1998
	Officer Robert Hayes	Albany PD	1998	
	Sergeant Lance Inman	Keizer PD	1998	1997
	Trooper Michael Iwai	SP	1999	
	Trooper Eric Judah	SP	1998	
	Officer Kristina Knox	Salem PD	1996	1997
	Officer David Leday	Keizer PD	1997	1998
	Officer Tim Lenihan*	Myrtle Creek PD	1996	1997
	Deputy Timothy McCall	Harney County SO	2000	1999
	Trooper David Peterson	SP	1996	
	Sergeant Robert Ruark	Polk County SO	2000	2001
	Lieutenant Trace Schreiner	DPSST	1998	1997
	officer Justin Stevenson	Dallas PD	2000	2000
	Officer K.T. Taylor	Sandy PD		1999
	Sergeant Tim Weaver*	Newberg PD	1999	1999
	Trooper Steve Webster	SP	1995	1995
Washington	Trooper James Aye	SP	1999	
	Trooper Curt Boyle	SP	1998	1998
	Trooper Nathan Elias	SP	2000	
	Trooper Steve Gardner	SP	1999	
	Trooper Darrell Hash	SP	1997	1998
	Officer Michael Henry	Puyallup PD	1997	1998
	Trooper Harlan Jackson	SP	1998	2001
	Officer Theresa Kubala	Vancouver PD	2000	2001
	Trooper Bruce Lantz	SP	1997	2001
	Trooper Darrin Latimer	SP	1998	
	Trooper Brian Mihelich	SP	2001	
	Trooper Shane Nelson	SP	2000	
	Trooper D.A. O'Neill	SP	1997	2000
	Officer Kelly Parsons	Walla Walla PD	1998	2001
	Deputy J. Sousley	Pierce County SO	1999	2000
	Trooper Keith Trowbridge	SP	1998	
	Trooper David Wilbur	SP	1998	1998
Idaho	Corporal Craig Boll	SP	1998	
	Trooper T.J. Harms	SP	2000	
	Trooper Timothy Horn	SP	1999	
	Sergeant Timothy Johnson	SP	1996	1998
	Trooper Edward Robertson	SP	1999	
	Corporal Lance Rogers	McCall PD	2000	2000

Test Postures

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, in that the subject stood with feet together, hands at the sides, and head upright and facing forward.

In the seated posture, the subject sat in an armless chair or folding chair with the head upright and turned approximately 45 deg to the side. All but one of the evaluators for this posture tested subjects with their heads turned to the left, as if the evaluator was approaching the vehicle from the driver's-side window. One left-handed evaluator found it easier to test subjects with their heads turned to the right; his data are not obviously different from those of the other evaluators and, thus, not separated or otherwise distinguished in the analyses below.

In the supine posture, the subject laid flat on his/her back atop stacked gym mats at a height of about 18 in (46 cm). Evaluators tested subjects from either the right or left side, depending on handedness and personal preference. The side from which the tests were conducted was not recorded, since subjects were instructed to keep their heads straight and in line with their bodies for most of the testing, and evaluators were instructed to perform the tests directly above the subjects.

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 measurement of an actual DUI suspect. Oregon requires a single reading, and Idaho requires two readings, using an Intoxilyzer 5000, while Washington requires two readings using a DataMaster. All Idaho and Washington measurements reported below are the averages of the respective readings for each subject.

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 portable breath test instrument so as to avoid possible contamination of the DataMaster instrument.

Test Procedures

Pre-Test

At the start of the eye movement tests of the SFST's, officers check for the presence of prescription glasses or contact lenses, and for ocular redness and excessive tearing. 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 report of "bloodshot, watery eyes" by an officer may suggest recent exposure of the subject to a noxious environment, such as a smoke-filled room, but also may occur in response to the dehydrating effects of alcohol intoxication.

Spectacles are removed during testing to allow the officer to see the subject's eyes when the stimulus is moved to extreme lateral and up-gaze positions. The officer typically confirms that the subject can see the stimulus, usually a pen, penlight, or finger, prior to 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. Anecdotal reports from officers suggest that dehydrated soft lenses may dislodge from the eye. Therefore, subjects should be encouraged to blink during testing, and, after the initial observation for redness and tearing, to use lubricating drops as necessary.

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. However, uncorrected high refractive error, astigmatism, anisometropia, amblyopia, 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, such as glaucoma, diabetes, vestibular diseases, multiple sclerosis, viral infections (e.g., cold or flu), etc., in the absence of medications that fall into any of the drug categories described above, do not produce eye movements that are similar to those observed with intoxication. Despite isolated research reports that have since been retracted[3]' or whose scientific methodology is seriously flawed,[32] fatigue has not been proven to produce or exaggerate eye movement test results that an experienced officer would mistake for intoxication.

HGN

Testing was conducted in the same manner in all test postures, consistent with NHTSA guidelines.[13] The subject's head is held straight, and the subject is directed to move only the eyes to follow the stimulus. The stimulus is positioned at midline, approximately 12 to 15 in (30 to 38 cm) from the subject's nose and slightly above eye level. This elevated eye position raises the upper lids slightly and allows the officer a better view of the eyes, but does not affect the results of the test. Likewise, the officer may ask the subject to lower the chin slightly to see the eyes more easily, with no consequence for the test.

The stimulus always is moved in a plane perpendicular to the midline, but could just as easily be moved along an arc at a constant distance from the nose, since all testing is based on angular position and speed. The subject's left eye is observed first during each of the three component tests.

Smooth pursuit is assessed first by moving the stimulus to extreme lateral left gaze, then to extreme lateral right gaze and back to midline, at about 30 deg/sec. The stimulus movement is smooth and continuous, and typically is performed twice, but may be repeated as necessary if the officer needs to confirm the findings. Endpoint nystagmus is assessed next for each eye by positioning the stimulus at the extreme lateral gaze while requiring the eye to maintain fixation for at least 4 sec. Gaze nystagmus is assessed third by moving the stimulus smoothly toward the lateral gaze position at about 15 deg/sec. If nystagmus is evident during the movement, the stimulus is stopped and maintained at that position to determine if the nystagmus is sustained for at least 4 sec. If the nystagmus is not sustained, the slow lateral movement is continued until either the nystagmus appears again or the stimulus reaches 45 deg with respect to midline. Officers easily estimate a 45-deg angle based on the position of the stimulus with respect to the subject's shoulder, and the fact that part of the temporal sclera should still be visible.

'The HGN test is scored by the total number of clues present for the two eyes, scoring one clue each per eye for lack of smooth pursuit, sustained nystagmus at maximum deviation, and onset of gaze nystagmus prior to 45 deg. The maximum number of clues is six. Previous laboratory and field validation studies demonstrated that the presence of four or more clues is highly correlated with BAC of either 0.10[18,19] or 0.08%.[33]

VGN

Testing was conducted in the same manner in all test postures, consistent with NHTSA guidelines.[13] The subject's head is held straight, and the subject is directed to move only the eyes to follow the stimulus. The stimulus is positioned at midline, approximately 12 to 15 in (30 to 38 cm) from the subject's nose and slightly above eye level. The stimulus is moved smoothly upward along a line perpendicular to the midline at about 15 deg/sec. The stimulus is held in the extreme up-gaze position for at least 4 sec, and sustained vertical nystagmus during that time indicates a positive result.

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.[13] PAN may be induced in an intoxicated individual when the head is tilted with respect to straight ahead, with the nystagmus present in primary gaze. The observed presence of PAN at any test posture is easily differentiated from gaze nystagmus.

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. In the supine posture, the subject simply turned the head to either side. In all test postures, the subject tried to maintain fixation on the stimulus held along the midline at 12 to 15 in (30 to 38 cm) from the nose. A positive result was recorded if the evaluator observed nystagmus during this gaze position.

LOC

Testing was conducted in the same manner in all test postures, but modified with respect to the DRE training manual.[30] The subject's head was held straight, and the subject was directed to move only the eyes to follow the stimulus. The stimulus was positioned at midline, approximately 12 to 15 in (30 to 38 cm) from the subject's nose and slightly above eye level. The stimulus was moved slowly in a clockwise or counterclockwise circle approximately the same size as the subject's face in a plane perpendicular to the midline, and then, in a continuous motion, slowly brought in along the midline to the bridge of the nose. If the subject was able to converge, the stimulus was held at the nose for about 1 sec.

In the standard procedure, a positive result is recorded when the subject's eyes lose convergence on the stimulus, either as the stimulus is moved in along the midline or during the 1-sec period when it is held at the bridge of the nose. In this study, evaluators were instructed to stop the stimulus at the point where convergence is first lost and to estimate the distance of the stimulus from the bridge of the nose, similar to the estimate of NPC in standard clinical practice. Evaluators did not use a ruler or other device to estimate the convergence distance, and the investigators did not confirm the estimates in any manner. For an average adult, the bridge of the nose is within about 0.5 in (13 mm) from the anterior surface of the eye,[34] or no more than 1 in (25 mm) from the center of rotation. This distance was not measured explicitly for the subjects in this study.

Evaluators also were asked to record which eye diverged first, or if both eyes diverged simultaneously during testing. However, the subject's eye dominance or preference was not assessed, and, thus, could not be correlated with the findings.

RESULTS

Demographic Data

Average age of all subjects was 29.0 years, range 21 to 62 years. There was no significant difference in subject ages based on gender ($p = 0.351$). As might be expected, there was a significant difference in subject weights based on gender ($p = 0$), with males consistently heavier than females.

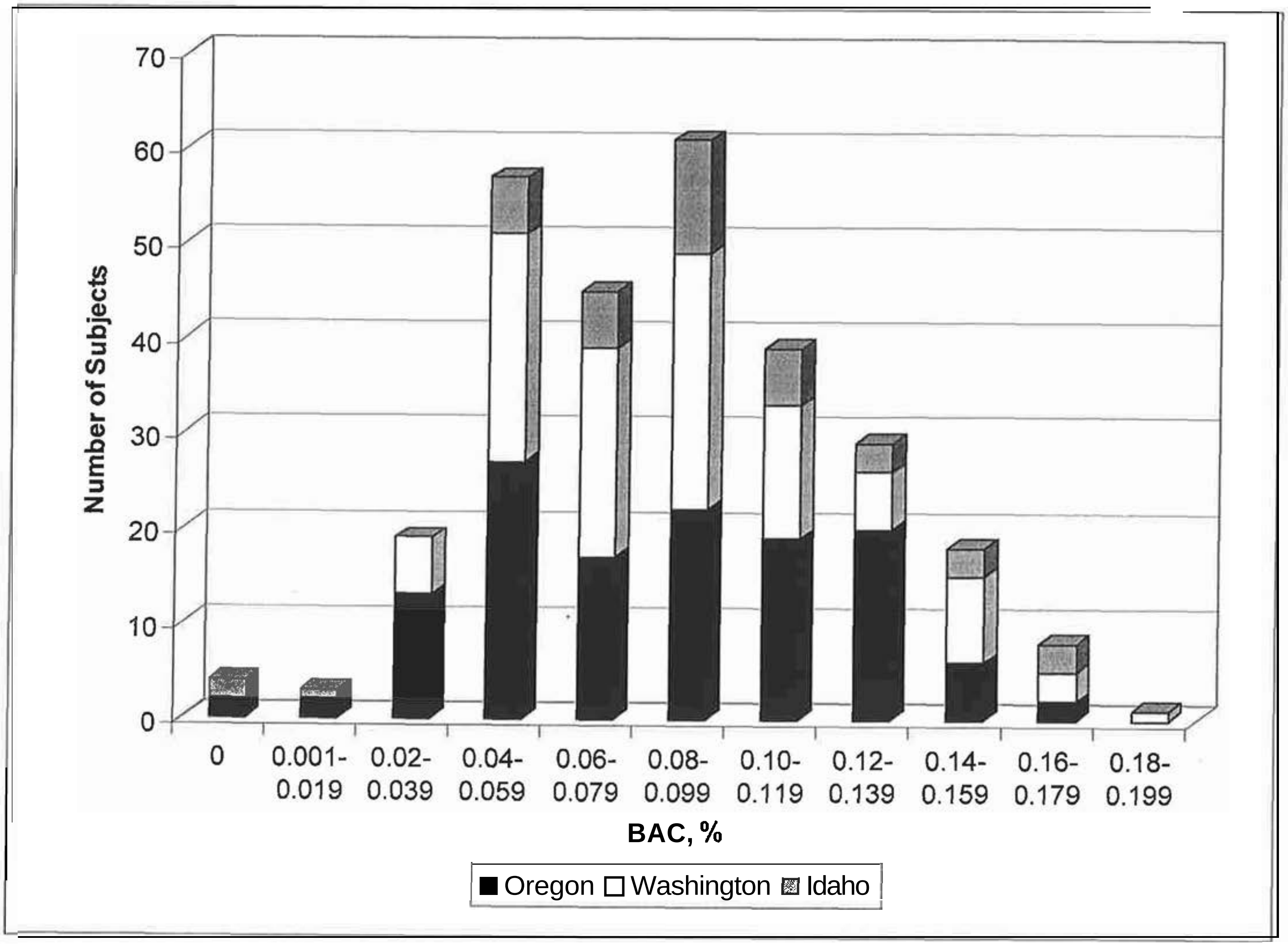
The high percentage of Caucasian subjects (97%) reflects the population of the Pacific Northwest. Follow-up studies with more ethnically-diverse populations are encouraged. Thirty-two subjects (33%) wore or reported the need to wear either spectacles or contact lenses for driving. Lens prescriptions 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 long-standing, 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*

Figure 1 shows the distribution of BAC's from all measurement times for all states. Of the 284 total measures, 156 (54.9%) were at 0.08% and higher, and 95 (33.5%) were at 0.10% and higher. The highest individual BAC's were 0.189% for a subject in Washington, 0.179% for an Idaho subject, and 0.176% for an Oregon subject.

Figure 1. Distribution of BAC's for all subjects at all test times for each state.



BAC measurements were taken toward the end or after each set of evaluations, on average between 4.5 and 23.5 min from the midpoint of any given set of evaluations. The longest time difference for an individual subject was about 50 min. Since the typical elimination rate of alcohol is about 0.015% per hour for an average adult,[35] the measured blood alcohol levels provide an accurate assessment of the intoxication of the subjects during each set of eye movement evaluations.

HGN

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

Baseline Evaluations of Sober Subjects

Of the 164 evaluations conducted at each test posture at baseline, fewer than 10% at any posture demonstrated one or more HGN clues. Table **3** shows the number of evaluations at each posture in which each component of the HGN test was observed in at least one eye. Chi-square analyses show that there are no significant differences based on test posture for lack of smooth pursuit, $\chi^2(4) = 2.30$, $p = 0.680$, nystagmus at maximum deviation, $\chi^2(4) = 7.96$, $p = 0.093$, and gaze nystagmus prior to 45 deg, $\chi^2(4) = 2.41$, $p = 0.660$.

Table **3.** Number of baseline evaluations at each test posture, in which the type and number of total HGN clues were observed.

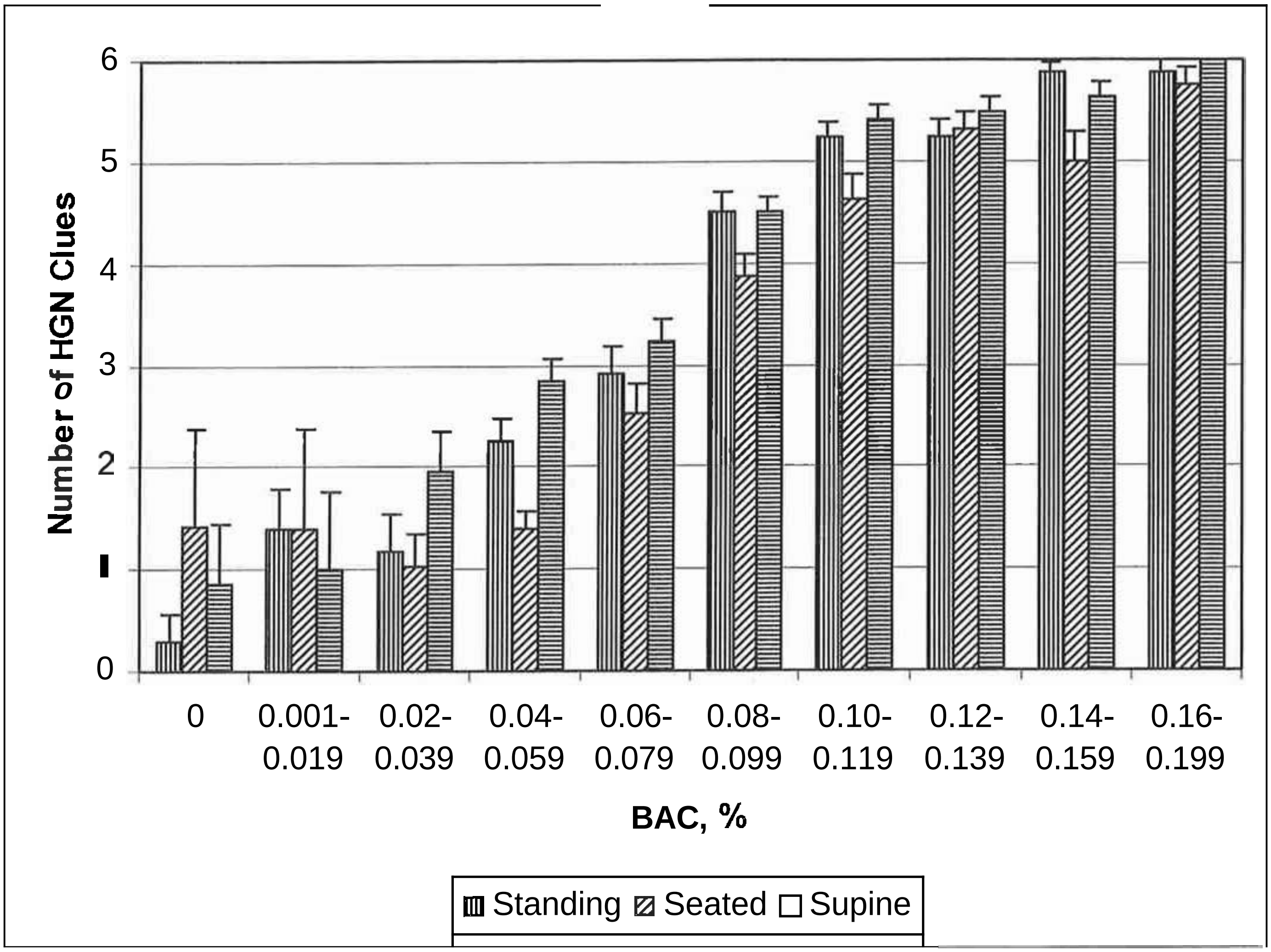
	Posture:	Standing	Seated	Supine
Type of Clue	Lack of Smooth Pursuit	4	2	2
	Endpoint Nystagmus	13	13	8
	Onset of Gaze Nystagmus Prior to 45 deg	3	2	1
Total Number of Clues	0	148	149	154
	1	7	10	3
	2	7	5	6
	3	1	0	1
	4	1	0	0
	5	0	0	0
	6	0	0	0

Table 3 also shows the number of evaluations at each test posture in which the given number of total HGN clues were observed. Only one evaluator observed four clues (endpoint nystagmus in both eyes and gaze nystagmus prior to 45 deg in both eyes) on a single subject in the standing posture. At no posture during the baseline evaluations were five or six clues observed on any subject. Chi-square analysis shows that there is no significant difference based on test posture for the number of HGN clues observed, $\chi^2(8) = 7.17$, $p = 0.518$.

Test Evaluations – Analyses by BAC and Number of Clues

Figure 2 shows the average number of HGN clues, and standard error of the mean, at each test posture and range of BAC's. 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 over 0.18% for a single measurement.

Figure 2. For each test posture and BAC range, average number of HGN clues observed at each BAC range, with standard error bars.



Compared to the standing posture, evaluators consistently observed fewer clues for the HGN test in the seated posture and more clues in the supine posture for subjects with BAC's over 0.02%. Chi-square analysis shows that there is a statistically significant difference in the number of HGN clues observed based on test posture, $\chi^2(12) = 45.49$, $p = 0$. However, the correlation coefficients, relating each subject's BAC to the number of clues observed by each evaluator, are remarkably similar: 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[36] reported a correlation coefficient of 0.65 between BAC and HGN tested in the standing posture. All correlations for the current study are statistically significant (p = 0) and not different from that of Stuster and Burns ($p > 0.18$).

Additional analyses involve the concepts of sensitivity, specificity, and accuracy. Sensitivity of a test, 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. On the other hand, specificity, also known as the true negative ratio, is the proportion of subjects who show 'a negative test result to all subjects who do not have the given condition. A test applied to subject populations where there is no overlap in results between subjects who have the given condition and those who do not would have both sensitivity and specificity equal to one, if the test is designed to detect the condition. Accuracy is the proportion of subjects correctly identified as having the condition and not having the condition to all subjects. A test is valid if it correctly and accurately differentiates the presence and absence of a condition.

The sensitivity, specificity, and accuracy of the HGN test at each test posture are shown in Table 4 for each of two criterion blood alcohol levels, 0.08 and 0.10%. In addition, Table 4 shows analyses of the field results of Good and Augsburger[14] for BAC of 0.10%,[a] which was the legal limit in Ohio at the time of that study. Note that for that study, HGN was conducted only in the standing posture.

Table 4. Sensitivity, specificity, accuracy, and area under the ROC curve calculations for HGN data at each test posture at two criterion blood alcohol levels (BAC), 0.08 and 0.10%. Included for comparison are calculations based on the data of Good and Augsburger.[14]

BAC:	0.08%			0.10%			
Posture:	Standing	Seated	Supine	Standing	Seated	Supine	Good & Augsburger
Sensitivity	0.890	0.799	0.891	0.956	0.887	0.969	0.963
Specificity	0.633	0.715	0.538	0.497	0.592	0.439	0.184
Accuracy	0.773	0.761	0.730	0.647	0.689	0.613	0.897
Area under ROC curve	0.832	0.812	0.795	0.794	0.791	0.791	0.725

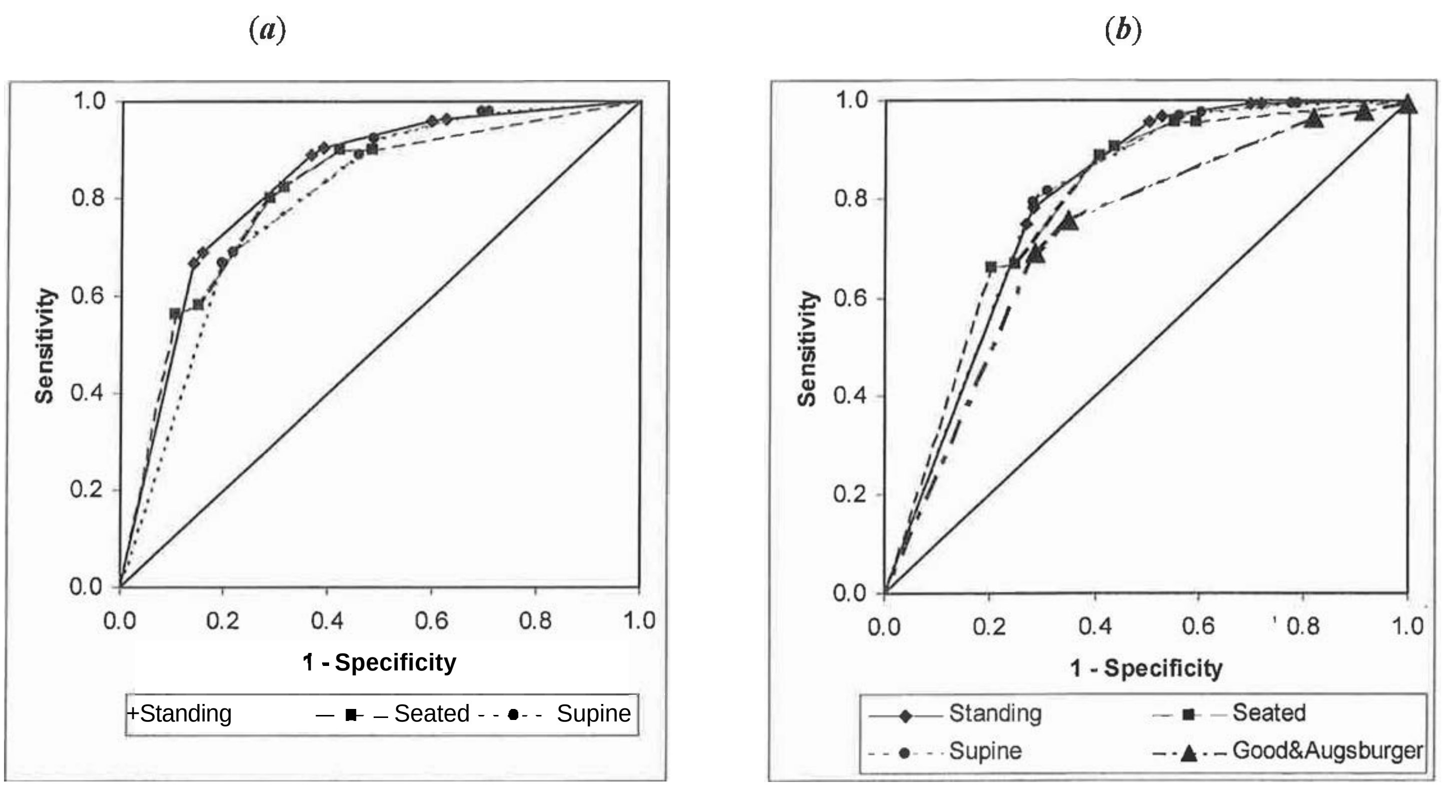
Depending on test posture, the HGN test correctly identified about 80 to 90% of subjects with blood alcohol levels of 0.08% or more, and about 54 to 72% of subjects with BAC below 0.08%, with an overall accuracy across all postures of 75%. For a blood alcohol level of 0.10%, the HGN test correctly identified 89 to 97% of subjects at or above that level, and 44 to 59% of subjects below that level, depending on the test posture, with an overall accuracy across all postures of 63%. By comparison, Good and Augsburger correctly identified 96% of subjects with BAC at or above 0.10%, but only 18% of subjects of subjects below 0.10%, with an overall accuracy of 90%.

At first glance, the results of the current study appear to vary widely and seem inconsistent with those of Good and Augsburger. However, the results may be analyzed by considering different criterion levels for the number of HGN clues, thus changing the sensitivity and specificity of the test. This allows us to plot a Receiver Operating Characteristic (ROC)

[a] This is the only previous study for which the data are reported to allow the following analyses.

curve (see Figure 3), which is one method commonly used to assess the diagnostic value of a test.[37] The actual values plotted are the sensitivity on the ordinate, and one minus the specificity, or the false positive ratio, on the abscissa. The better the diagnostic value of a test, the closer the ROC curve will be to the upper left comer; a test that cannot discriminate between the presence and absence of the given condition performs no better than chance and will have an ROC curve that lies along the diagonal.

Figure 3. Receiver Operating Characteristic (ROC) curves for HGN at BAC criterion levels of (a) 0.08% and (b) 0.10%. See text for description.



ROC analysis may be applied to parametric and non-parametric data, and the area under the curve corresponds to the probability of the test in correctly identifying positive and negative results, thereby giving an indication of the quality of the test.'' For non-parametric data, such as the number of HGN clues observed, a conservative estimate of the area is achieved by calculating the trapezoidal areas under neighboring points.[39] A perfect test will have an area of one, or a 100%-discrimination probability, whereas a test performing at chance will have an area of 0.5, or a 50%-discrimination probability. For BAC criterion levels of 0.08 and 0.10%, the areas under the ROC curves are above 0.79 for all test postures. By comparison, the area under the curve for the data of Good and Augsburger is 0.73.

Inter-Evaluator Reliability

Since most workshops involved six evaluators, i.e., two evaluators at each test posture, results from each pair of evaluators can be compared. For psychomotor tests, such as HGN and VGN, a highly reliable test has a test-retest reliability of about 0.7.[40] Reliability was assessed by determining how many pairs of evaluators concurred on observing or not observing at least four HGN clues. For the standing, seated, and supine test postures, test-retest reliabilities were 0.59, 0.65, and 0.71, and test-retest accuracies were 76, 73, and 85%, respectively. By comparison, the HGN test conducted in the standing posture previously has been shown to have test-retest reliability between officers of 0.59;[19] this is not significantly different from any coefficient for the current study ($p > 0.40$).

Discrimination of BAC Below 0.08%

Stuster and Burns[36] suggested that the SFST's could be used to reliably detect intoxication at a blood alcohol level of 0.04%. These tests would aid in the proper identification of intoxicated commercial drivers, as well as intoxicated passenger vehicle drivers in jurisdictions that have adopted or will adopt legal limits of BAC below 0.08%. Likewise, they could be used to help enforce zero-tolerance statutes in those jurisdictions where a driver below the legal drinking age may not have a non-zero BAC.

For discrimination of intoxication at BAC of 0.04%, Stuster and Burns limited their analyses to 83 cases with BAC below 0.08%. The only revision to the SFST battery was to lower the MGN criterion from four clues to two clues. The observation and scoring of the other tests were not changed. Based on results of all three SFST's, Stuster and Burns reported sensitivity of 0.94, specificity of 0.52, and accuracy of 80%.

In the current study, at each test posture, 40 evaluations were conducted on subjects with BAC's below 0.04%, and 180 on subjects at or above 0.04% and below 0.08%. Using the two-clue criterion level for HGN, and averaging across all test postures, sensitivity is 0.62, specificity is 0.63, and accuracy is 62%. Based on a BAC criterion level of 0.05% for these data (89 evaluations with BAC below 0.05%, 131 evaluations with BAC between 0.05 and 0.08%), average sensitivity increases to 0.69, average specificity is virtually unchanged at 0.61, and average accuracy increases to 66%. Table 5 shows the sensitivity, specificity, accuracy, and area under the ROC curve for each test posture at blood alcohol levels of 0.04 and 0.05%.

Table 5. Sensitivity, specificity, accuracy, and area under the ROC curve calculations for HGN data at each test posture at two criterion blood alcohol levels (BAC), 0.04 and 0.05%.

BAC:	0.04%			0.05%		
Posture:	Standing	Seated	Supine	Standing	Seated	Supine
Sensitivity	0.657	0.442	0.746	0.729	0.526	0.835
Specificity	0.675	0.675	0.550	0.602	0.739	0.523
Accuracy	0.661	0.484	0.710	0.674	0.606	0.706
Area under ROC curve	0.695	0.593	0.672	0.693	0.670	0.697

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 intoxication is achieved, as defined for the individual subject. VGN may be present when other CNS depressant drugs, inhalants, or PCP are used, either separately or in combination, or with alcohol.

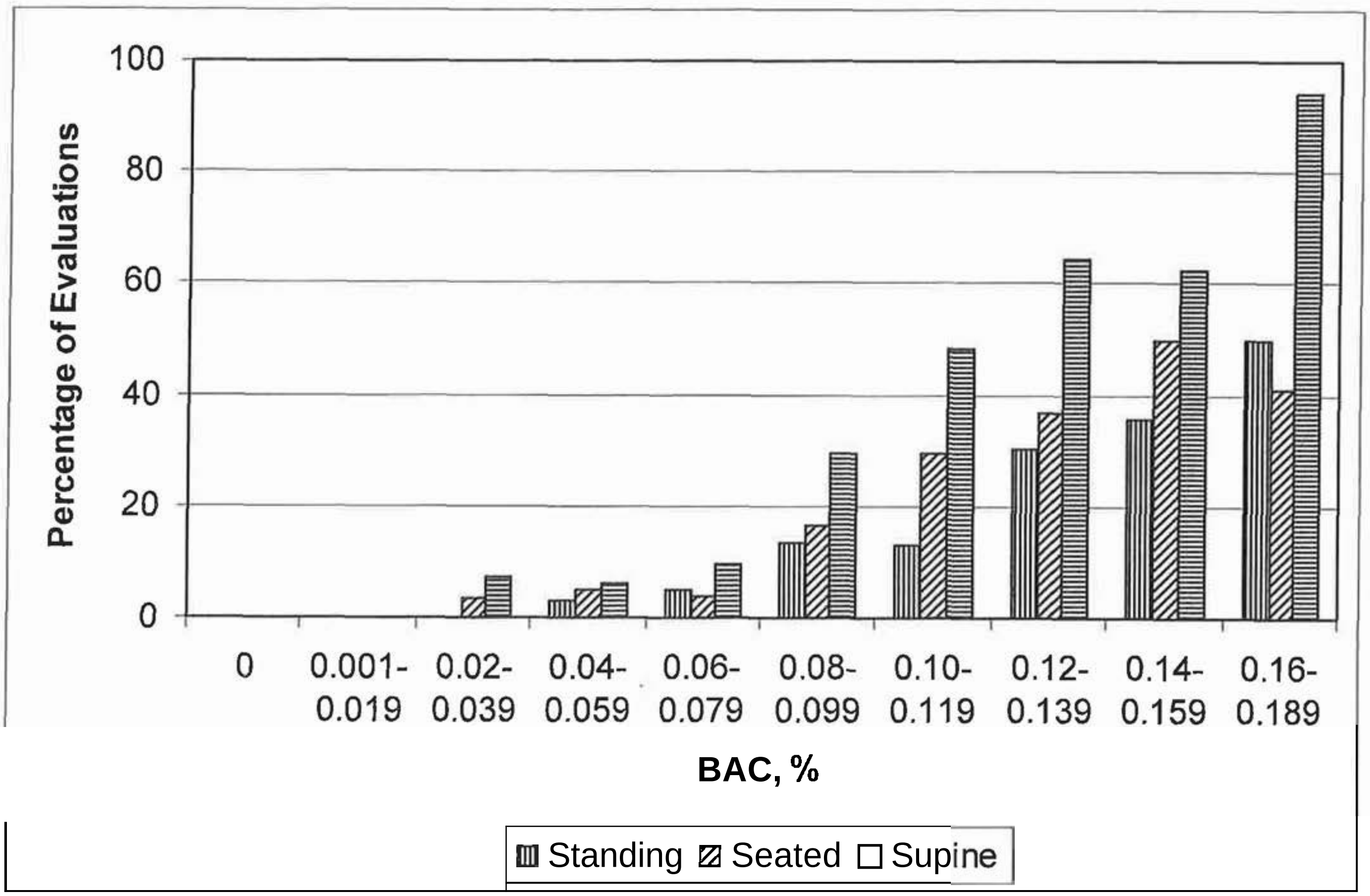
Baseline Evaluations of Sober Subiects

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 evaluation, when the subject had a blood alcohol level of 0.02%, nor was it observed by any other evaluator in any other test posture either at baseline or the first evaluation.

Test Evaluations – Analysis bv BAC

Figure 4 shows the percentage of evaluations at which VGN was observed at each test posture for the given BAC ranges. Compared to the standing posture, VGN typically was observed more frequently in the seated and supine postures. Chi-square analysis shows that there is a statistically significant difference in the observation of VGN based on test posture, $\chi^2(2) = 44.43$, $p = 0$. However, the correlation coefficients, relating each subject's BAC to the observation of VGN by each evaluator, are similar: for the standing posture, $r = 0.35$; for the seated posture, $r = 0.37$; and for the supine posture, $r = 0.52$. All of these coefficients are statistically significant ($p = 0$).

Figure 4. Percentage of evaluations at each test posture in which VGN was observed for the given BAC ranges.



Of the 221 evaluations conducted at each test posture on subjects with blood alcohol levels below 0.08%, VGN was observed only on 7 subjects (3.2%) in the standing posture, 9 subjects (4.1%) in the seated posture, and 16 subjects (7.2%) in the supine posture. Chi-square analysis shows that there is no significant difference in the number of observations at the test postures, $\chi^2(2) = 4.38$, $p = 0.112$. On the other hand, for subjects with blood alcohol levels 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 blood alcohol levels of 0.10% and higher, the percentages of observations at each posture were 26.8, 37.1, and 61.0%, respectively. Observation of VGN at the test postures is significantly different at each criterion BAC, $\chi^2(2) = 46.37$, $p = 0$, and $\chi^2(2) = 40.19$, $p = 0$, respectively.

Table 6. Sensitivity, specificity, and accuracy calculations for VGN data at each test posture at two criterion blood alcohol levels (BAC), 0.08 and 0.10%.

BAC:	0.08%			0.10%		
Posture:	Standing	Seated	Supine	Standing	Seated	Supine
Sensitivity	0.215	0.289	0.485	0.268	0.371	0.610
Specificity	0.968	0.959	0.928	0.935	0.920	0.856
Accuracy	0.560	0.594	0.687	0.718	0.739	0.775

Table 6 shows the sensitivity, specificity, and accuracy for each test posture at blood alcohol levels of 0.08 and 0.10%. While the sensitivities are all relatively low, the specificities are excellent, and the accuracies are very good.

Inter-Evaluator Reliability

Reliability between evaluators was determined as for HGN above. Reliability was assessed by determining how many pairs of evaluators concurred on observing or not observing VGN. For the standing, seated, and supine test postures, test-retest reliabilities were 0.37, 0.40, and 0.52, and test-retest accuracies were 85, 83, and 80%, respectively.

PAN

PAN originally was considered to be a very sensitive diagnostic assessment of alcohol intoxication.[41] 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 a head tilt by the subject unintentionally may induce PAN, which may confound or exacerbate the other eye movements that the officer is testing.

Results and analyses 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, specificity, accuracy, and inter-evaluator reliability. For the interested reader, those values are very similar to those reported for VGN above.

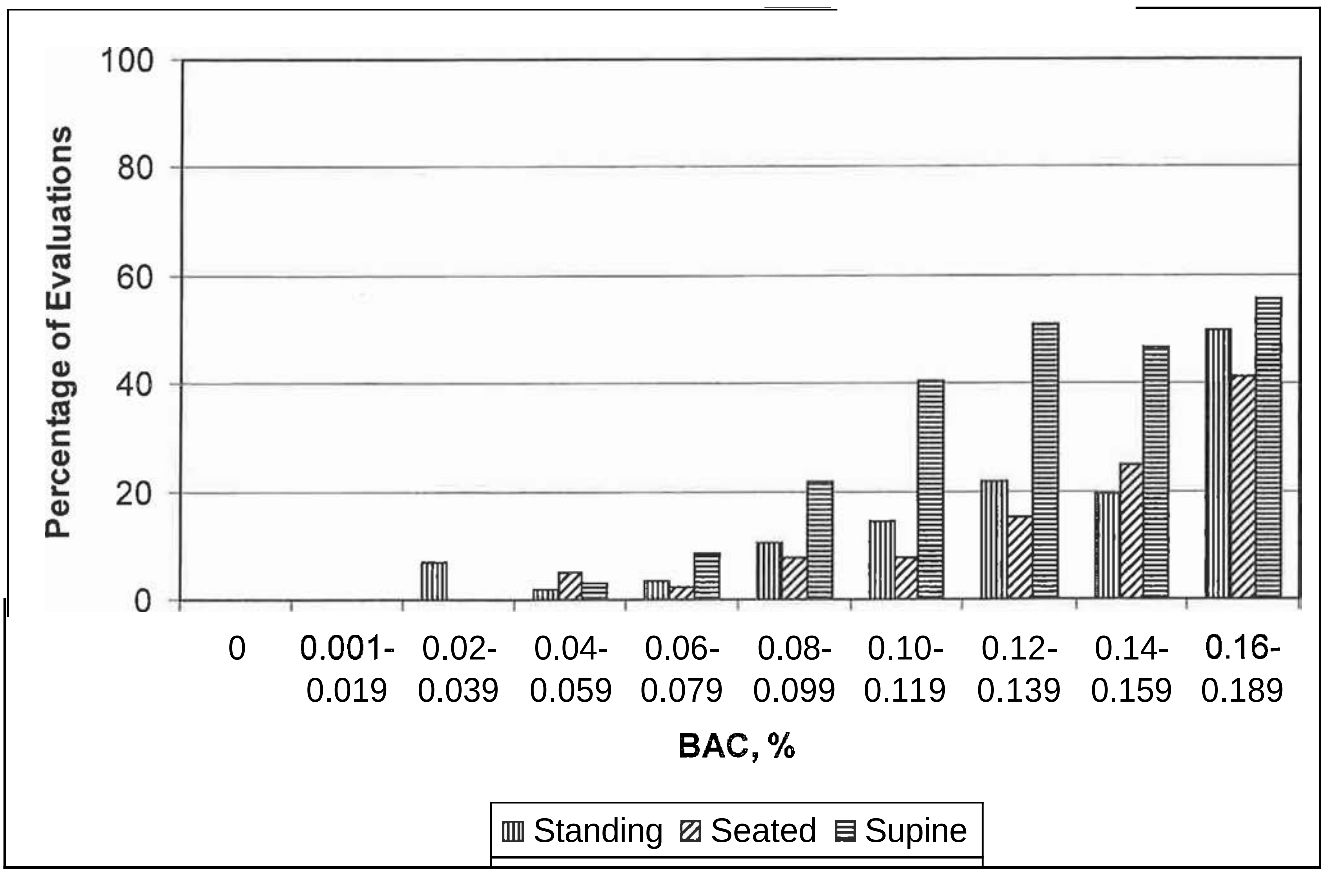
Baseline Evaluations of Sober Subiects

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

Figure 5 shows the percentage of evaluations at which PAN was observed at each test posture for the given BAC ranges. Overall, PAN was observed with approximately equal frequency in the standing and seated postures, but with greater frequency in the supine posture. Chi-square analysis shows that there is a statistically significant difference in the observation of PAN based on test posture, $\chi^2(2) = 41.80$, $p = 0$.

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



LOC

Baseline Evaluations of Sober Subjects

Table 7 shows the mean distance estimates, with respect to the bridge of the nose, for NPC for all subjects at baseline. Based on the inability to converge the eyes to the bridge of the nose, more than one-half of all subjects exhibited LOC at least once at each test posture. Alternately, since most subjects were evaluated twice at each test posture, LOC was observed during nearly one-half of all evaluations at each posture. Chi-square analyses show that neither of the differences in observations of LOC at the different test postures are significant, either in number of subjects, $\chi^2(2) = 4.37$, $p = 0.112$, or number of evaluations, $\chi^2(2) = 3.10$, $p = 0.213$.

Table 7. Baseline estimates of nearpoint of convergence (NPC), with respect to the bridge of the nose, for 164 evaluations on 96 subjects at each test posture; number and percentage of subjects who exhibited Lack of Convergence (LOC) at least once at each test posture, based on inability to converge the eyes to the bridge of the nose; and number of evaluations during which the left eye, right eye, and both eyes were observed to first lose convergence.

Posture:	Standing	Seated	Supine
NPC			
mean, in (cm)	1.59 (4.04)	1.38 (3.51)	1.25 (3.18)
s.d., in (cm)	2.17 (5.51)	2.44 (6.20)	1.86 (4.72)
LOC Observed			
Subjects	59 (61.5%)	50 (52.1%)	64 (66.7%)
Evaluations	81 (49.4%)	66 (40.2%)	78 (47.6%)
First Eye to Lose Convergence			
Right Eye	37	34	40
Left Eye	30	15	23
Both Eyes	10	17	15

Table 7 also shows the number of evaluations during which the left eye, right eye, and both eyes were observed to first lose convergence. Note that the totals at each test posture occasionally sum to less than the number of times LOC was observed; some evaluators did not record which eye diverged first. Chi-square analysis shows that there is no significant difference in which eye is observed to lose convergence first, based on test posture, $\chi^2(4) = 6.27$, $p = 0.180$.

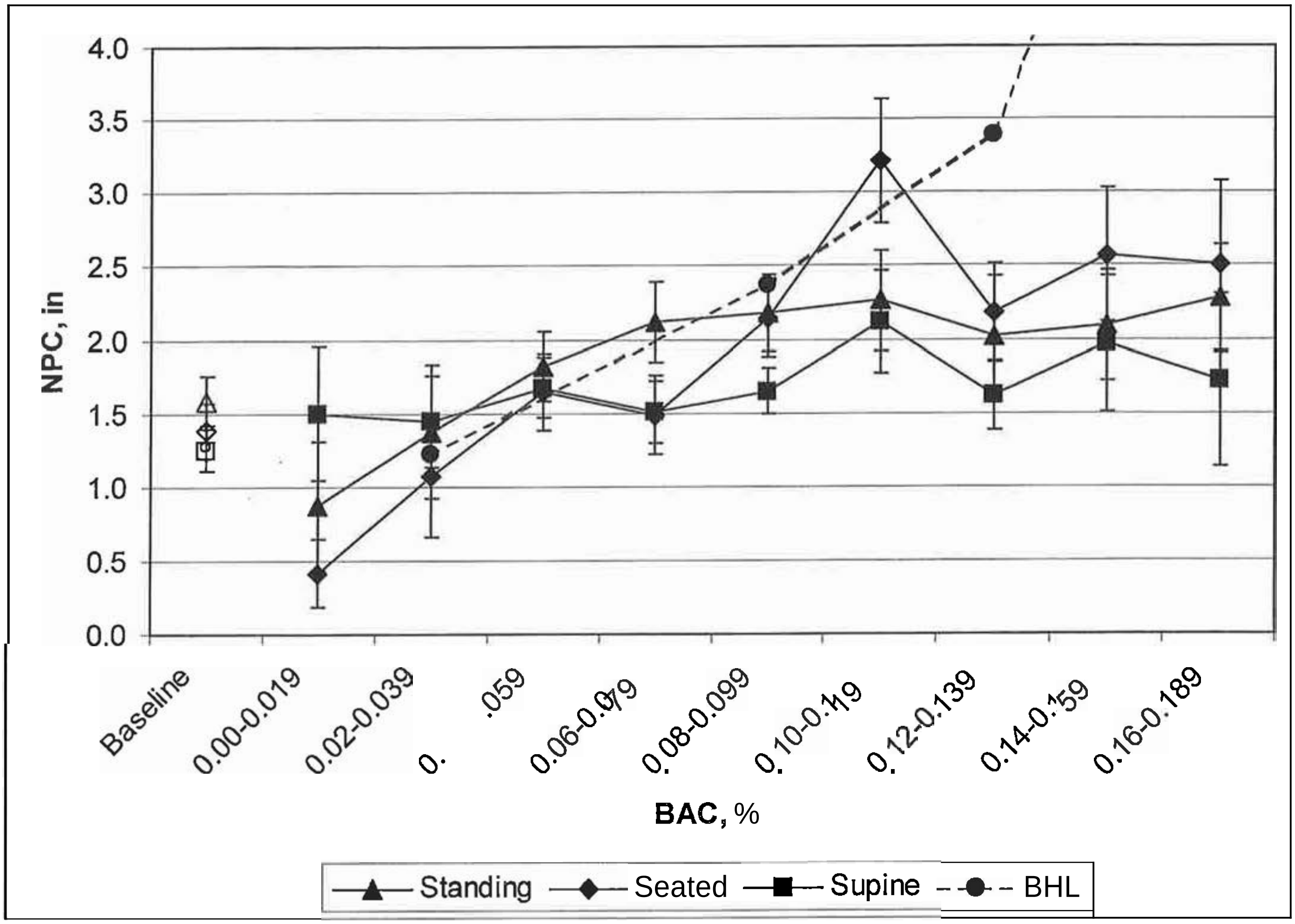
If the LOC criterion distance is changed to an estimated 3 in (8 cm) from the bridge of the nose, the numbers of positive findings decrease, to 29.9, 20.1, and 22.0% of evaluations in the standing, seated, and supine postures, respectively. The 3-in distance is consistent with the expected convergence ability of normal individuals. Based on this criterion distance, the average percentage of evaluations in which LOC was observed, 24.0%, is closer to the 10-15% estimate of normal individuals who cannot converge their eyes. As before, chi-square analysis shows that the differences in number of evaluations during which LOC was observed, are not significant, $\chi^2(2) = 4.84$, $p = 0.089$.

There is no significant correlation between NPC and age for the subjects in this study at any test posture for either criterion distance, most likely because of the relatively narrow range of subject ages, average 29.0 yrs, standard deviation (s.d.) 8.2 yrs, with only five subjects aged 45 yrs or older.

Test Evaluations – Analysis by BAC

Figure 6 shows mean NPC and standard error, with respect to the bridge of the nose, for each BAC range for each test posture, as well as NPC at baseline. Results are grouped in BAC ranges of 0.02%, except for the highest range, which includes one subject who achieved a BAC above 0.179%, namely 0.189%. Based on mean values for each BAC range, analysis of variance shows that there is no significant difference between test postures, $F(2,16) = 0.98$, $p = 0.397$.

Figure 6. Mean NPC, with respect to the bridge of the nose, at each test posture for each BAC range indicated, with standard error bars. Also shown are the data of Brecher et al.,[27] calculated with respect to the bridge of the nose. Open symbols = baseline data; closed symbols = test data.

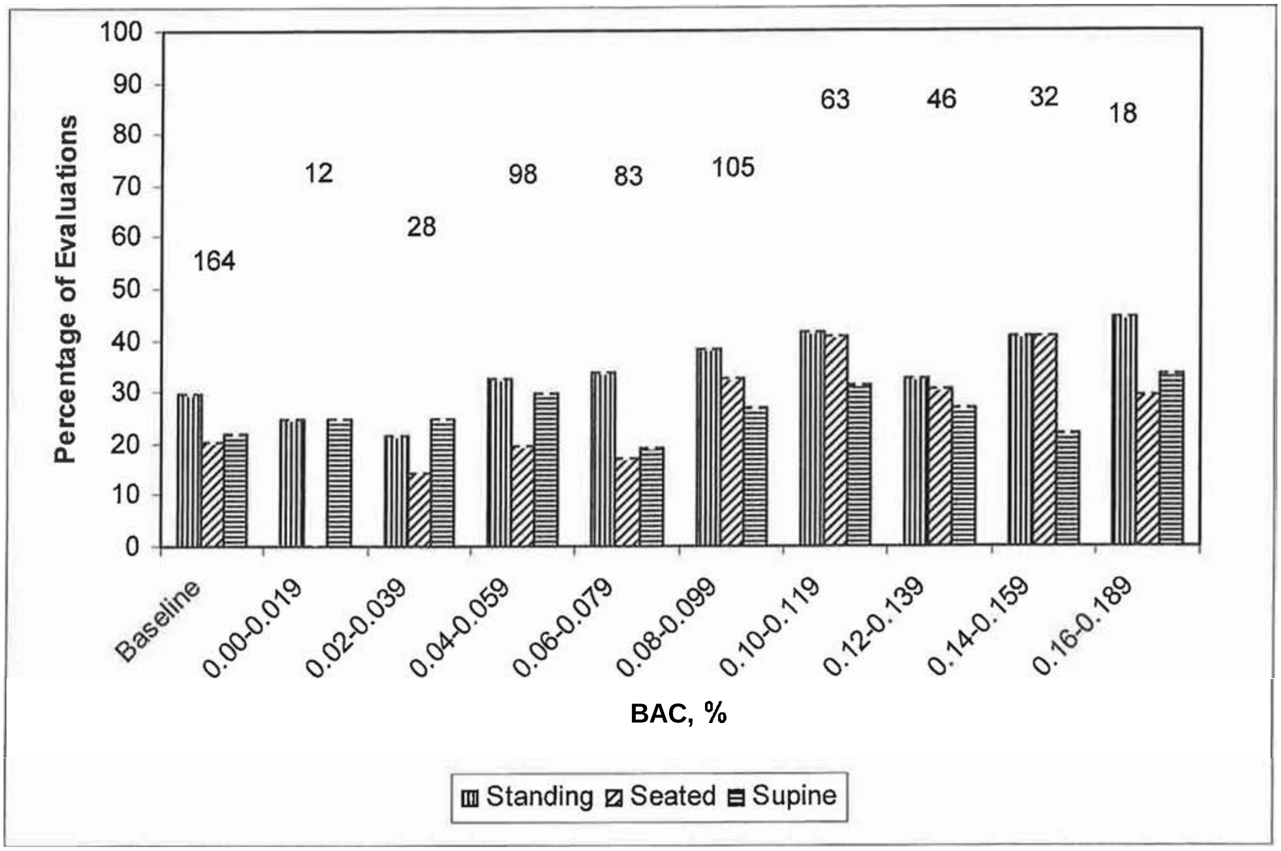


For the standing and seated postures, linear regression shows that the slopes of the best-fit lines are significantly different from zero, $p = 0.001$ and $p = 0$, respectively, and that the correlations between NPC and BAC are strong and statistically significant, $r = 0.799$, $p = 0.010$, and $r = 0.832$, $p = 0.005$, respectively. However, for the supine posture, the slope is not significantly different from zero, $p = 0.056$, and the correlation, though moderate in strength, is not significant, $r = 0.600$, $p = 0.088$.

The results of Brecher et al.[27] also are presented in Figure 6, calculated with respect to the bridge of the nose. Note that Brecher et al. tested 14 subjects at baseline and four BAC ranges, and that the mean NPC for the highest BAC range, 0.16-0.20%, was about 7.4 in (18.8 cm) (not shown in Figure 6). Hogan and Linfield[28] and Hogan and Gilmartin[29] each tested only 10 subjects at baseline and a single BAC range, approximately 0.06-0.08%. Average NPC's and s.d.'s, calculated with respect to the bridge of the nose for the 20 subjects in the two studies, are 1.59 ± 0.65 in (4.04 ± 1.65 cm) at baseline and 2.37 ± 0.80 in (6.01 ± 2.03 cm) with intoxication.

Figure 7 shows the percentage of evaluations for each test posture and each BAC range at which LOC was observed, based on criterion distances of bridge of the nose (i.e., 0 in) and 3 in (8 cm) from the nose. Also shown are the number of evaluations conducted per test posture for each BAC range. Based on percentage values for the 3-in criterion distance for each BAC range, analysis of variance shows that there is a significant difference between test postures, $F(2,16) = 4.84$, $p = 0.023$. At most BAC ranges, LOC is observed less frequently in the supine posture than either the standing or seated postures.

Figure 7. Percentage of evaluations during which LOC was observed at each test posture for each BAC range indicated. Wide bars indicate LOC with respect to criterion distance of **3** in (8 cm); narrow bars indicate LOC with respect to the bridge of the nose. Values for each set of bars specify total number of evaluations conducted at each test posture for that BAC range.



For the standing and seated postures, linear regression shows that the slopes of the best-fit lines are significantly different from zero, $p = 0$ for both, and that the correlations between percentage of subjects exhibiting LOC and BAC are strong and statistically significant, $r = 0.857$, $p = 0.003$, and $r = 0.818$, $p = 0.007$, respectively. However, for the supine posture, even though the slope is significantly different from zero, $p = 0.001$, the correlation is weak and not significant, $r = 0.322$, $p = 0.398$. Table 7 shows the sensitivity, specificity, and accuracy of the LOC at the two BAC criterion levels, 0.08 and 0.10%, and for the two criterion distances, bridge of the nose and 3 in (8 cm) from the nose.

Table 7. Sensitivity, specificity, and accuracy calculations for LOC data at each test posture at two criterion blood alcohol levels (BAC), 0.08 and 0.10%, and at two criterion distances, Bridge of the Nose and 3 in from Nose.

	BAC:	0.08%			0.10%		
Criterion Distance	Posture:	Standing	Seated	Supine	Standing	Seated	Supine
Bridge of Nose	Sensitivity	0.667	0.746	0.636	0.667	0.811	0.616
	Specificity	0.425	0.509	0.335	0.396	0.458	0.334
	Accuracy	0.557	0.638	0.499	0.485	0.574	0.427
3 in from Nose	Sensitivity	0.290	0.278	0.203	0.292	0.307	0.205
	Specificity	0.781	0.889	0.814	0.760	0.850	0.809
	Accuracy	0.522	0.584	0.478	**0.612**	**0.695**	**0.606**

There is a significant difference in the eye first observed to lose convergence, when comparing baseline evaluations with the total number of non-zero BAC test evaluations, $\chi^2(10) = 148.98$, $p = 0$. During the baseline evaluations, regardless of test posture, evaluators observed the left eye to lose convergence more often than the right eye or both eyes. This may be due to the subjects' eye dominances or preferences, or to the fact that officers are taught to observe the left eye first during other testing. In the seated posture, evaluators may have had difficulty observing the eye opposite the head turn (i.e., the subject's right eye for all but one evaluator). Nonetheless, during the test evaluations, evaluators at the seated posture more frequently observed both eyes diverge, while evaluators at the supine posture observed the left and right eyes diverge with almost equal frequency. We cannot explain these variations based on our data, and suggest that future studies investigate this further.

Inter-Evaluator Reliability

The reliabilities between evaluators in observing LOC are low, varying from 0.26 to 0.32 for the bridge-of-the-nose criterion, and from 0.27 to 0.47 for the 3-in criterion, at the different test postures. The reliabilities in estimating distances are also low, varying from 0.32 to 0.54. Nonetheless, all of the reliabilities are significantly different from zero ($p = 0$). Some of the variability in the observation of BAC may be due to the speed at which the stimulus is moved toward the eyes, and the difficulty in estimating distances.

The correlation coefficients for each pair of test postures range from 0.29 to 0.50, all of which are significant ($p = 0$). Thus, even though the estimated distances vary somewhat, as demonstrated by the moderate coefficients, there is consistency between measures at the different postures.

Discrimination of BAC Below 0.08%

Brecher et al.[27] reported that voluntary convergence ability does not seem to be impaired at BAC's below 0.03%, and Stuster and Burns[42] suggested that Standardized Field Sobriety Tests could be used to reliably detect intoxication at a blood alcohol level of 0.04%. These tests would aid in the proper identification of intoxicated commercial drivers, as well as intoxicated passenger vehicle drivers in jurisdictions that have adopted or will adopt legal limits of BAC below 0.08%. Likewise, they could be used to help enforce zero-tolerance statutes in those jurisdictions where a driver below the legal drinking age may not have a non-zero BAC.

Similar to the analyses of Stuster and Bums, analyses were performed only on evaluations where BAC is below 0.08%. In the current study, at each test posture, 40 evaluations were conducted on subjects with BAC's below 0.04%, and 180 on subjects at or above 0.04% and below 0.08%. Alternately, 89 evaluations were conducted with BAC’s below 0.05% and 131 evaluations with BAC's between 0.05 and 0.08%. Table 9 shows the sensitivity, specificity, and accuracy for each test posture for each criterion distance and blood alcohol level.

Table 9. Sensitivity, specificity, and accuracy calculations for LOC data at each test posture at two criterion blood alcohol levels (BAC), 0.04 and 0.05%, and at two criterion distances, Bridge of the Nose and 3 in from Nose.

	BAC:	0.04%			0.05%		
Criterion Distance	Posture:	Standing	Seated	Supine	Standing	Seated	Supine
Bridge of Nose	Sensitivity	0.613	0.528	0.680	0.659	0.527	0.689
	Specificity	0.600	0.675	0.400	0.551	0.562	0.371
	Accuracy	0.611	0.555	0.629	0.615	0.541	0.561
3 in from Nose	Sensitivity	0.239	0.125	0.188	0.277	0.140	0.197
	Specificity	0.859	0.940	0.821	0.855	0.928	0.828
	Accuracy	0.365	0.289	0.308	0.530	0.470	0.458

DISCUSSION

Consistent with previously published results, we confirm the validity of the HGN test in the standing posture to discriminate intoxication at criterion 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. Also consistent with previously published results, we confirm the validity of the HGN test in any posture to discriminate intoxication at criterion blood alcohol levels of 0.04 and 0.05%.

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 clues, rather than to the incorrect identification of PAN or to any other influence of the vestibular system. Evaluators conducting the test in the seated posture occasionally reported difficulty seeing the subject's eye that was opposite the head turn (the right eye for all but one evaluator). 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 intoxicated seated subjects would be mistaken as sober, nor that sober supine subjects would be mistaken as intoxicated. As shown in Figure 2, evaluators typically observed fewer than two clues on subjects with BAC's below 0.04%, and four or more clues on subjects with BAC's at 0.10% and above, regardless of posture. For subjects with BAC's between 0.08 and 0.10%, evaluators observed, on average, about 4.5 clues in the standing and supine postures and 3.9 clues in the seated posture. While statistically significant, these differences are not "clinically" significant 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 such 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 employed in the current study; such a minor change in posture will not affect the results.

We also confirm that the VGN test can be used to identify high levels of intoxication 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 4, less than 10% of subjects with BAC's below 0.08% exhibited VGN at any posture, whereas at least 30% of subjects with BAC at and above 0.12% exhibited VGN.

Consistent with previously published results, we find that NPC does not change appreciably with respect to baseline for BAC below 0.04%, with an average value of less than 1.6 in (4 cm) from the nose for any test posture. Based on a criterion distance of 3 in (8 cm) from the nose, we find that presence of LOC at baseline for all test postures is only somewhat greater than might be expected in a normal adult population, 24.0% versus 10-15%. Likewise, for BAC below 0.04%, LOC was observed in only 18.5% of all evaluations at all test postures.

As shown in Figures 6 and 7, NPC recedes and presence of LOC increases with increasing blood alcohol level, regardless of test posture. Nonetheless, the smallest changes in both measures occur in the supine posture. During the actual evaluation of a suspect, testing in the supine posture would occur only when the individual is secured in a gurney or backboard at the scene of an accident. In all other situations, the suspect is able to either stand or sit, and the overall results are essentially identical for these postures.

Based on the bridge-of-the-nose distance criterion for LOC, about half to two-thirds of all subjects with BAC below either 0.08 or 0.10% would be classified as intoxicated. With the 3-in distance criterion, sensitivities decrease and specificities increase for all test postures at any BAC criterion. Overall, accuracies remain about the same, roughly at 0.5. While the farther distance criterion does not appreciably improve the accuracy of the test, it does considerably reduce the number of false positives, from an average of 59.1% to 18.3%, for all test postures. Similar reductions in false positive rates are achieved when evaluating subjects with BAC below either 0.04 or 0.05%, from an average of 47.4% to 12.8%, for all test postures.

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 intoxicated with alcohol at BAC’s of 0.04% and higher. Our findings also suggest that the LOC test criterion distance be changed from the bridge of the nose to approximately **3** in (8 cm) from the nose. With such a change, findings for sober individuals are more consistent with expected values; for intoxicated individuals, sensitivity decreases to about 0.3, but specificity increases to at least 0.76 for BAC at or above 0.08%, and to at least 0.82 for BAC of 0.04 or 0.05%. Thus, officers would record significantly fewer false positive results.

We conclude that the proper use of the LOC test at any test posture will help an officer correctly identify individuals intoxicated with alcohol.

By extension, since other CNS depressants, inhalants, phencyclidine, and certain antihistamines affect the same neural centers as alcohol, DRE officers may use these tests to aid in identifying intoxication with substances other than, or in addition to, alcohol.

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REFERENCES

1. Michie J. First-time study highlights need for increased awareness of substance use and driving behaviors. *http://www,health.org/pressrel/dec98/10.htm*, Dec. 26, 1998.

2. Kennedy RS, Turnage JT, Rugotzke GG, Dunlap WP. Indexing cognitive tests to alcohol dosage and comparison to standardized field sobriety tests. *J Stud Alcohol* 1994; 55: 615-628.

3. Kosnoski EM, Yolton RL, Citek K, Hayes CE, Evans RB. The drug evaluation classification program: using ocular and other signs to detect drug intoxication. *J Am Optom Assoc* 1998; 69: 211-227.

4. Bigelow GE, Bickel WE, Roache JD, Liwbson IA, Nowowieski P. Identifying types of drug intoxication: laboratory evaluation of a subject-examination procedure. DOT HS-806-753. National Technical Information Service, Springfield, VA, 1985.

5. Adler EV, Burns M. Drug recognition expert (DRE) validation study. Arizona Governor's Office of Highway Safety, 1994.

6. Smith JA, Hayes CE, Yolton RL, Rutledge DA, Citek K. Drug recognition expert evaluations made using limited data. In press.

7. Council on Scientific Affairs. Alcohol and the driver. *JAMA* 1986; 255: 522-527.

8. National Highway Traffic Safety Administration. On DWI laws in other countries. NHTSA Traffic Tech Number 221, May 2000.

9. Robinson DA. Eye movement control in primates. *Science* 1968; 161: 1219-1224.

10. Abel LA, Parker L, Daroff RB, Dell'Osso LF. End-point nystagmus. *Invest Ophthalmol Vis Sci* 1978; 17: 539-544.

11. Dell'Osso LF, Daroff RB. Nystagmus and saccadic intrusions and oscillations. In: *Duane's Clinical Ophthalmology* 1997; 2(11).

12. Fregly AR, Bergstedt M, Graybiel A. Relationships between blood alcohol, positional alcohol nystagmus and postural equilibrium. Q *J Stud Alcohol* 1968; 28: 11-21.

13. National Highway Transportation Safety Administration. DWI detection and standardized field sobriety testing student manual, 2000.

14. Good GW, Augsburger AR. Use of horizontal gaze nystagmus as a part of roadside sobriety testing. *Am J Optom Physiol Opt* 1986; 63: 467-471.

15. Halperin E, Yolton RL. Is the driver drunk? Oculomotor sobriety testing. *J Am Optom Assoc* 1986; 57: 654-657.

16. Adler EV, Burns M. Drug recognition expert (DRE) validation study. Arizona Governor's Office of Highway Safety, 1994.

17. Smith JA, Hayes CE, Yolton RL, Rutledge DA, Citek K. Drug recognition expert evaluations made using limited data. In press.

18. Bums M, Moskowitz H. Psychophysical tests for DWI arrest. DOT HS-802-424. National Technical Information Service, Springfield, VA, 1977.

19. Tharp V, Burns M, Moskowitz H. Development and field test of psychophysical tests for DWI arrest. DOT HS-805-864. National Technical Information Service, Springfield, VA, 1981.

20. Bigelow GE, Bickel WE, Roache JD, Liebson IA, Nowowieski P. Identifying types of drug intoxication: laboratory evaluation of a subject-examination procedure. DOT HS-806-753. National Technical Information Service, Springfield, VA, 1985.

21. Resolution 6: Horizontal gaze nystagmus as a field sobriety test. *J Am Optom Assoc* 1993; 64: 653.

22. Owens DA, Leibowitz HW. Perceptual and motor consequences of tonic vergence. In: *Vergence Eye Movements: Basic and Clinical Aspects.* Boston: Butterworths, 1983: 25-74

23. von Noorden GK. Binocular vision and ocular motility: theory and management of strabismus, 4th ed. St. Louis: CV Mosby, 1990: 195-196.

24. Grosvenor T. Primary care optometry, 4th ed. Boston: Butterworth-Heinemann, 2002: 143.

25. Scheiman M, Gallaway M, Coulter R, Reinstein F, Ciner E, Herzberg C, Parisi M. Prevalence of vision and ocular disease conditions in a clinical pediatric population. *J Am Optom Assoc* 1996; 67: 193-202.

26. Michaels DD. Visual optics and refraction: a clinical approach, 3rd ed. St. Louis: CV Mosby, 1985: 426.

27. Brecher GA, Hartman AP, Leonard DD. Effect of alcohol on binocular vision. Am **J** *Ophthalmol* 1955; 39(II): 44-52.

28. Hogan RE, Linfield PB. The effects of moderate doses of ethanol on heterophoria and other aspects of binocular vision. Ophthal Physiol Opt 1983; 3: 21-31.

29. Hogan RE, Gilmartin B. The relationship between tonic vergence and oculomotor stress induced by ethanol. Ophthal Physiol Opt 1985; 5: 43-51.

30. National Highway Transportation Safety Administration. Drug evaluation and classification training program: The drug recognition expert school; student manual, 1999.

31. Tharp VK. Gaze nystagmus as a roadside sobriety test. Abstracts and Reviews in Alcohol and Driving 1981; 2: 5-8.

32. Booker JL. End-position nystagmus as an indicator of ethanol intoxication. Science & Justice 2001; 41: 113-116.

33. Anderson TE, Schweitz RM, Snyder MB. Field evaluation of a behavioral test battery for DWI. DOT HS-806-475. National Technical Information Service, Springfield, VA, 1983.

34. Tilley AR. *The measure of man and woman: human factors in design.* New York: Henry Dreyfuss Associates, 1993: 15.

35. Julien RM. *A Primer of Drug Action.* New York: WH Freeman, 2001: 56-58.

36. Stuster J, Bums M. Validation of the standardized field sobriety test battery at BACs below 0.10 percent. Santa Barbara, CA: Anacapa Sciences, Inc., August 1998.

37. Beck JR, Schultz EK. The use of relative operating characteristic (ROC) curves in test performance evaluation. *Arch Pathol Lab Med* 1986; 110: 13-20.

38. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology* 1982; 143: 29-36.

39. Centor RM, Schwartz JS. An evaluation of methods of estimating the area under the receiver operator characteristic (ROC) curve. *Med Decis Making* 1985; 5: 149-156.

40. Bruning JL, Kintz BL. *Computational Handbook of Statistics* 3rd ed. Glenview, Illinois: Scott, Foresman and Co., 1987: 226.

41. Aschan G, Bergstedt M, Goldberg L, Laurell L. Positional nystagmus in man during and after alcohol intoxication. Q *J Stud Alcohol* 1956; 17: 381-405.

42. Stuster J, Burns M. Validation of the standardized field sobriety test battery at BACs below 0.10 percent. Santa Barbara, CA: Anacapa Sciences, Inc., August 1998.