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PAPER

GENERAL; TOXICOLOGY

Karl Citek,[1] *O.D., Ph.D.; Ashlee D. Elmont,*[2] *O.D.; Christopher L. Jons,*[3] *O.D.; Chad J. Krezelok,*[4] *O.D.; Joseph D. Neron,*[5] *O.D.; Timothy A. Plummer*[6]*; and Timothy Tannenbaum*[7]

Sleep Deprivation Does Not Mimic Alcohol Intoxication on Field Sobriety Testing*

ABSTRACT: Previous research shows that sleep deprivation (SD) produces cognitive impairment similar to that caused by alcohol intoxication. Individual studies suggest that SD also causes deficits in motor skills that could be mistaken for intoxication. Consequently, SD often is used as a defense when an impaired driver is charged with driving while intoxicated. Twenty-nine adult subjects participated in two test sessions each, one after a full night's rest and the other after wakefulness of at least 24 h. Subjects consumed prescribed amounts of alcohol during each session. Law enforcement officers conducted field sobriety tests identical to those with which a driver would be assessed at roadside. Researchers also measured clinical responses of visual function and vital signs. The presence and number of validated impairment clues increase with increasing blood alcohol concentration but not with SD. Thus, SD does not affect motor skills in a manner that would lead an officer to conclude that the suspect is intoxicated, unless intoxication also is present.

KEYWORDS: forensic science, sleep deprivation, fatigue, alcohol, intoxication, field sobriety test, nystagmus, blood alcohol concentration, driving while intoxicated

Sleep deprivation (SD) greatly increases the risk of motor vehicle crashes (1–6), but jurisdictions in the United States and around the world are only recently beginning to establish legal consequences for drowsy or sleep-deprived driving (7–9, http://www.drowsydriving.org/docs/DrowsyDrivsing Prevention Week 2008 Press Release.pdf). Many people either are unaware of the danger of driving with SD or endure it as part of their occupations (10–16). To assist drivers who may be drowsy, an in-vehicle monitoring system has been developed and finally introduced on production vehicles (17, http://www.mbusa.com/mercedes/#/advancedTechOverview/press/).

SD produces impairment similar to alcohol intoxication based on assessments of cognitive and cognitive-motor function (18–25) and simulated driving performance (26,27). SD significantly impairs attention skills in all individuals, with young drivers more affected than older drivers on tests of reaction time (28). Useful visual field decreases with age (29) and intoxication (30), and SD causes further reduction regardless of age (31). While the specific driving skills (32–34) and physiological mechanisms (35) affected by SD and intoxication may differ, even low levels of alcohol intoxication combined with partial or full SD cause substantial decrements in simulated driving performance (36–40).

[1]Pacific University College of Optometry, 2043 College Way, Forest Grove, OR.
[2]Private Practice, Boulder, CO.
[3]Private Practice, Buffalo, WY.
[4]Private Practice, Bozeman, MT.
[5]Private Practice, Beaverton, OR.
[6]Oregon State Police, Salem, OR.
[7]Washington County (Oregon) Sheriff's Office, Hillsboro, OR.
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SD has been shown to affect saccadic eye movements (41,42), pupil size in total darkness (43), pupil reaction to light (41,44) and emotional stimuli (45,46), and blink rate (47). All of these studies also report subjective changes in perception of sleepiness at different levels of SD. Except for pupil reaction to light, law enforcement officers do not assess any of these physiological factors on suspected impaired drivers (48,49).

Several reports suggest that SD directly produces changes in visuomotor functions that could be mistaken as being caused by intoxication (42,50,51). Additional studies suggest that SD exacerbates or prolongs the effects of intoxication on eye movements (52–54). Consequently, SD often is offered as a defense when an impaired driver is charged with driving while intoxicated (DWI). (Note that different jurisdictions may use different, but related, legal terms, such as driving under the influence [DUI], driving under the influence of intoxicants [DUII] or operating [a vehicle] while intoxicated [OWI].) As most jurisdictions do not yet make it a crime to drive sleep deprived, an intoxicated driver could escape severe legal and civil penalties if he can convince the judge and jury that he merely was tired.

Many law enforcement officers have reported to the authors that they can distinguish between intoxicated and sleep-deprived drivers. However, no prior research has assessed SD under the actual psychophysical procedures used by officers to evaluate driver impairment, known as field sobriety tests (FSTs). In addition, doctors occasionally are asked to testify about an officer's findings, but their expertise may be limited to clinical testing, which often is different in procedure (including test protocol and equipment or instruments used), expected findings, and interpretation. The goal of this research is to determine whether SD causes changes in performance on FSTs and related clinical tests in a manner that could be confused with intoxication.

Note that *fatigue* often is used as a synonym for SD. However, it also can be defined as specific changes in physiological or cognitive performance, responsiveness or appearance following continued exertion or stimulation, such as in the well-known phenomenon *fatigue nystagmus* (55). Because such changes typically are unrelated to those observed with SD, and to avoid confusion, we will not use the term *fatigue* in place of SD.

Methods

Subjects

Potential subjects were either students at Pacific University, Forest Grove, Oregon, or friends or spouses of students, comprising a sample of convenience. Before beginning the study, candidates reviewed and signed informed consent and model release forms, approved by the Pacific University Institutional Review Board. Candidates completed a detailed questionnaire regarding personal and health histories and experience with consuming alcohol. Those who admitted to a history of alcohol or substance abuse, use of certain medications, pregnancy, or presence of any medical condition with which alcohol consumption is contraindicated were excluded from the study. Individuals who were excessively over- or underweight, as determined by body mass index of >40 or <18, respectively, likewise were excluded for health reasons. One male subject taking medication for hypertension was allowed to participate subsequent to his doctor's approval; the medication was not known to have contraindications for alcohol use nor cause any side effects that would confound the results.

Each subject was asked to participate in two test sessions at least 1 week apart, one after a full night's rest and the other after wakefulness of at least 24 h. Subjects were arbitrarily assigned to each session based on availability.

Twenty-nine subjects (14 women, 15 men) qualified for and completed the study. Their demographic information is provided in Table 1. All were 21 years of age or older, as confirmed by a valid driver's license. Only one subject was over 34 years of age, but the results of this sole 52-year-old female subject are consistent with those of the other subjects, so there is no reason to isolate or exclude her data. Two subjects are authors of this study; the remaining 27 subjects each received a $20 gift card for their participation.

TABLE 1—*Demographic data for subjects who completed the study.*

	Female	Male
Number	14	15
Age, years		
Mean	27.3	25.45
Standard deviation	7.92	2.24
Range	21–52	22–30
Weight, kg		
Mean	59.8	83.0
Standard deviation	6.61	17.67
Range	50.0–75.0	61.4–136.4
Body mass index		
Range	18.9–27.5	19.4–39.7
Hours awake at start of workshop		
Normal sleep		
Mean	4.0	4.1
Standard deviation	1.59	1.73
Range	2.0–7.2	2.5–7.9
Sleep deprived		
Mean	30.3	29.4
Standard deviation	0.80	1.80
Range	28.8–32.1	24.4–31.9

Breath Analysis

A calibrated breath analysis instrument, Intoxilyzer 5000 (CMI, Owensboro, KY), identical to one used for actual DWI investigations in Oregon was used to estimate each subject's blood alcohol concentration (BAC) multiple times throughout each session, as indicated below. A researcher certified under Oregon guidelines to operate the instrument collected all the BAC data. Oregon Administrative Rules require that "[t]he operator is certain that the subject has not taken anything by mouth..., vomited, or regurgitated liquid from the stomach into mouth, for at least 15 min before taking the test" (http://arcweb.sos.state.or.us/rules/OARS_200/OAR_257/257_030.html). The study protocol described below allowed for testing to be completed during the required 15-min "deprivation period" prior to each breath test, as well as to ensure that each test was conducted in close proximity to its respective breath test.

Evaluators

Six law enforcement officers volunteered as evaluators for FSTs. All officers were certified Drug Recognition Experts (DREs) with extensive experience in identifying and assessing impaired drivers. The number of evaluators at each test session varied based on their availability and the number of subjects present, and most evaluators participated in multiple sessions. Researchers assessed vital signs and clinical tests as described below. Test order varied based on the availability of subjects, evaluators, and researchers within each test session.

FSTs

FSTs were conducted using procedures identical to those with which an impaired driver would be assessed. The tests included horizontal gaze nystagmus (HGN), vertical gaze nystagmus (VGN), walk-and-turn (WAT), one-leg stand (OLS), Romberg balance (RB), and lack of convergence (LOC). HGN, VGN, WAT, and OLS comprise the standardized FSTs that an officer typically would use to assess an impaired driver at roadside (48,56); these tests, as well as RB, LOC, vital sign evaluations (see below), and others not evaluated in this study, are part of the drug evaluation conducted by DREs (49,57). In all but two sessions, individual evaluators assessed only either of the following test combinations: HGN/VGN/LOC or WAT/OLS/RB. In the remaining two sessions, each of the two evaluators at each session conducted all of the assessments on half of the subjects.

The HGN test is comprised of three subtests, the results of which were each recorded separately for each eye tested: lack of smooth pursuit (LSP); distinct and sustained nystagmus at maximum deviation (DSNMD); and onset of nystagmus prior to 45 degrees (ONP45). Details of the test procedures, scoring, and interpretation of the HGN and VGN tests are described elsewhere (48).

Details of the test procedures and scoring of the WAT and OLS tests also are described elsewhere (48). For the OLS test, evaluators recorded both the validated clues observed (OLS clues) and the number to which the subject counted during the 30-sec test interval (OLS count). For the RB test, evaluators determined the presence of side-to-side, front-to-back, and circular sway (RB sway); the presence of leg, body, and eyelid tremors (RB tremors); and the actual time it took subjects to estimate the passage of 30 sec with eyes closed (RB time). Normal range of RB time is 25–35 sec (49). To avoid practice effects, WAT, OLS, and RB were assessed only at the beginning and end of each session; subjects specifically

were told not to perform or practice these tasks at times other than when they were being evaluated.

When this study was conducted, the procedure for the LOC test was to assess whether the subject could converge the eyes to a stimulus brought along the midline to the bridge of the nose (58). Since then, the procedure has been changed to assess convergence only to within 2 in. (5 cm) from the bridge of the nose (51). Even so, we believe that our results are valid, especially because we compared subjects to their own performance at baseline and we conducted a related clinical test at the same time.

Vital Signs

Blood pressure (BP) was measured manually with a calibrated sphygmomanometer and stethoscope; normal ranges for systolic and diastolic BP are 120–140 and 70–90 mmHg, respectively (49). Pulse rate was measured at the radial artery for 30 sec and multiplied by two to arrive at beats per min (bpm); normal range is 60–90 bpm (49).

Pupil size varies with light level and other factors, such as convergence and emotional arousal. Typical room light provides illuminance of 300–500 lux, and a dimmer room is expected to result in larger pupils. Pupil size was measured for both eyes using calibrated cards with either circles or semi-circles in diameters from 1.0 to 9.0 mm in 0.5-mm increments; normal range in room light is 2.5–5.0 mm (49). The test facility did not have a readily accessible "dark room" to allow us to evaluate, in a timely manner, pupil sizes and responses under the additional light conditions specified within the DRE protocol.

Clinical Tests

Researchers performed additional tests similar to the manner in which they are conducted clinically. Nearpoint of convergence (NPC) is related to the LOC test, except that the actual distance is recorded when the subject loses convergence; normal breakpoint is 5 cm from the bridge of the nose (59). Endpoint nystagmus (EN) involves the observation of any nystagmus at extreme lateral gaze of either eye. It is distinguished from DSNMD by the fact that EN usually is of small amplitude and possibly difficult to observe (60,61), hence not *distinct*, and of short duration, typically dissipating after 1–2 sec (50,62), hence not *sustained*.

Horizontal attentional field of view (AFOV) was assessed with an arc perimeter with 30-cm radius. The subject binocularly fixated a central spot 1.4 deg in diameter. A second target, also 1.4 deg in diameter, was introduced in the far periphery of either eye and manually moved toward the center at a speed of about 2 deg/sec until the subject first reported seeing it. Consequently, AFOV represents the lateral peripheral awareness for the left and right eyes together.

Overnight Observation Period

All but three subjects assigned to be awake for at least 24 h prior to a test session arrived at Pacific University College of Optometry at about 10 PM on the evening before the session, after a full day of classes or work. Subjects stayed in the student lounge area and were allowed to study, play games, and watch movies throughout the night, monitored by shifts of researchers. Subjects and monitors were provided with snack and breakfast foods, soft drinks, and water. The remaining three subjects worked in an overnight medical clerical office away from campus. These subjects monitored themselves for wakefulness, as well as performing the regular checks of vital signs described below.

Each subject's vital signs—BP, pulse rate, pupil sizes in room light—were checked four times at regular intervals throughout the overnight period, between about 10 PM and 11 AM. Lighting in the student lounge area was less than about 100 lux during the night, i.e., before 7 AM, for the first three measurements. For the last measurement after 8 AM, natural light, but no direct sunlight, entered the southward-facing windows, thereby increasing ambient light level to about 200–300 lux. Lighting in the medical office for the three respective subjects was similar, and their data are included with those of the other subjects.

Test Sessions

Alcohol dosing and testing was conducted in a training room at Washington County Sheriff's Office in Hillsboro, Oregon. A total of nine sessions were held either on a Friday or Saturday afternoon, commencing between about 12 Noon and 1 PM, based on availability of subjects and the facility. Subjects were requested to have at most a light breakfast no sooner than about 3 h prior to the start of a test session. Sleep-deprived subjects, except for the three medical office workers, were driven from Forest Grove to Hillsboro, about 6 miles, by the researchers. Well-rested subjects, as well as the three subjects who worked in the medical office overnight, provided their own transportation to the facility. Sessions finished between about 3:30 and 5 PM. All subjects had designated drivers available to take them home after each session, regardless of their BACs at the end of the session.

Evaluators were not told whether subjects were well rested or sleep deprived. Subjects did not interact with evaluators and researchers other than for testing purposes. Subjects, evaluators, and researchers (other than the lead researcher and breath test operator) were masked to the BAC readings. Evaluators and researchers did not confer regarding their findings. Evaluators and researchers used separate check-off and fill-in datasheets for each group of subjects tested at each test period, turning those in to the lead researcher at the end of the period to avoid comparison of current and previous findings.

Each subject received a prescribed total dose of 80-proof liquor of his or her choice (vodka, gin, rum, or whiskey). The dose was based on the subject's gender, weight, and intended BAC after 2 h of drinking, as calculated using a formula given by Jones (63). The dose was divided into two equal portions, usually with water added to mask the actual amount of alcohol being served. Subjects could add ice and as much of any mixer they wanted (orange juice, tonic water, cola, etc.) to each portion.

Three subjects within each state of restedness were maintained as placebo drinkers, receiving just enough alcohol to create a breath odor of alcohol and the impression that they were drinking like their fellow subjects. Fellow subjects, evaluators, and researchers (other than the lead researcher and breath test operator) were masked as to the identities of the placebo drinkers. For nonplacebo drinkers, the intended goal at the end of 2 h of drinking was BAC of between 0.08 and 0.11 g/dL.

Test Periods

All vital signs and test measures were assessed at the start of each session (baseline), before the consumption of any alcohol. Each subject began each session with a BAC of 0.00 g/dL, confirmed with the Intoxilyzer 5000, and with no other intoxicating drugs present, based either on self-report or on observation during the overnight period.

Subjects were requested to consume the first portion of the alcohol dose within the first 45 min after the start of drinking. To

maximize alcohol absorption, subjects were not allowed to eat any food during this time. All vital signs and test measures, other than WAT, OLS, and RB, were assessed after the first portion of alcohol was consumed (first period). Thus, subjects' BACs were measured about 1 h after starting drinking.

Subjects were requested to consume the second portion of the alcohol dose within the first 45 min of the second hour of the session. Subjects now were allowed to eat snack foods during this period. As before, all vital signs and test measures, except for WAT, OLS, and RB, were assessed after the second portion of alcohol was consumed (second period). Consequently, subjects' BACs were measured about 2 h after starting drinking.

After the second period, subjects enjoyed snack foods and soft drinks, but no alcohol, for an additional 45 min. After this time, all vital signs and test measures, now including WAT, OLS, and RB, were assessed once more (final period). Therefore, subjects' BACs were measured at least 1 h after drinking was finished.

Data Analysis

Data were analyzed for main effects of restedness and BAC with SPSS 17.0 (SPSS Inc., Chicago, IL). Variation of BAC within test sessions was analyzed using repeated-measures analysis of variance. Generalized estimating equations for ordinal logistic data were used to analyze HGN and its subtests (LSP, DSNMD, ONP45), WAT, OLS clues, RB sway, RB tremor, and EN. Generalized estimating equations for binary logistic data were used to analyze VGN and LOC. A linear mixed model was used to analyze OLS count, RB time, systolic and diastolic BP, pulse rate, pupil size, NPC, and AFOV. Additional analyses are reported below in the respective sections in Results.

For illustrative purposes in the figures only, data from the tests are combined for all subjects within the normal sleep and sleep-deprived conditions, and, other than the baseline results, grouped in BAC increments of 0.04 g/dL. Vital sign data from overnight periods are included in the respective figures for completeness but, except for pupil size, were not subjected to statistical analysis with respect to the test session data.

Results

Figure 1 shows the average BAC for all subjects at each test period. The highest BAC reached by a single subject at one period was 0.115 g/dL. There are no significant differences in BAC based on gender, $F_{1,27} = 2.80$, $p = 0.106$, restedness, $F_{1,27} = 2.16$, $p = 0.154$, or the interaction of gender and restedness, $F_{1,27} = 0.08$, $p = 0.774$. As expected, BAC varies significantly with test period, $F_{2,154} = 172.4$, $p < 0.0005$.

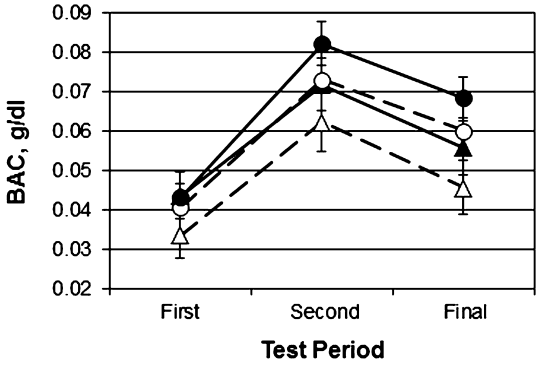


FIG. 1—*Average blood alcohol concentration (BAC), in g/dL, at each test period by gender across sessions. Standard error bars indicated. Open symbols: normal sleep; filled symbols: sleep deprived. Triangles: females; circles: males.*

Table 2 summarizes the results of the analyses of the FSTs, vital signs, and clinical tests described below, based on the statistical analyses conducted.

FSTs

Figure 2 shows the average number of HGN clues, out of a maximum of six. Consistent with previous research (56,62), subjects with BAC < 0.08 g/dL exhibited on average fewer than four clues, while subjects at 0.08 g/dL and above exhibited on average four or more clues. Statistical analyses show that the total number of HGN clues and the number of clues on each subtest increase with BAC but do not vary significantly with restedness (see Table 2). Likewise, McNemar tests of baseline data demonstrate that there is no significant difference in performance on any subtest based on restedness: LSP, $\chi^2(1) = 1.00$, $p = 0.317$; DSNMD, $\chi^2(1) = 1.60$, $p = 0.206$; and ONP45, $\chi^2(1) = 0$, $p = 1.00$.

Figure 3 shows the percentage of subjects who exhibited VGN. VGN typically is present with certain drugs (57) or at a high BAC for the individual (62) in the presence of at least four clues on the HGN test. On average, fewer than 25% of subjects with nonzero BAC under 0.08 g/dL exhibited VGN, while 40% of subjects with BAC at or above 0.08 g/dL exhibited VGN. Statistical analysis shows that the presence of VGN increases with BAC but does not vary significantly with restedness (see Table 2). Evaluators of two of the 29 subjects (6.9%) after normal sleep observed VGN at the baseline assessment, i.e., at BAC of 0.00 g/dL. Interestingly, one of these evaluators did not observe VGN on one of the subjects after the first period of the session, and neither subject exhibited VGN at the baseline assessment following SD.

Figure 4 shows the average number of WAT clues, out of a maximum of eight. Consistent with previous research (56), subjects with BAC < 0.08 g/dL exhibited on average fewer than two clues, while subjects at 0.08 g/dL and above exhibited on average two or more clues. Statistical analysis shows that the number of WAT clues increases with BAC but does not vary significantly with restedness (see Table 2).

Figure 5*a* shows the average number of OLS clues, out of a maximum of four. Consistent with previous research (56), subjects with BAC < 0.08 g/dL exhibited on average fewer than two clues. Interestingly, even subjects at 0.08 g/dL and above exhibited on average fewer than two clues, although the variances are greater than for subjects with BAC under 0.08 g/dL. Statistical analysis shows that the number of OLS clues increases with BAC but does not vary significantly with restedness (see Table 2).

Figure 5*b* shows the average number to which subjects counted during the OLS test. While this is not one of the validated clues of the OLS test, officers frequently record the results to demonstrate how suspects perform on this cognitive task, especially if suspects miscount or make other mistakes. Statistical analysis shows that OLS count does not vary significantly with BAC but does decrease with SD (see Table 2), from an overall mean (stdev) of 25.8 (3.65) when well rested to 23.8 (3.73) when sleep deprived.

Figure 6*a* shows the average number of RB sway and tremor clues. Statistical analysis shows that the average number of sway clues increases significantly with intoxication but does not vary significantly with restedness. Neither SD nor alcohol intoxication are expected to cause tremors, but intoxication with other drugs (57) or

TABLE 2—*Results of statistical tests for main effects of restedness and blood alcohol concentration (BAC).*

	Change with Restedness?		Change with BAC?	
	Statistic Value	*p* Value	Statistic Value	*p* Value
Field sobriety tests				
Horizontal gaze nystagmus†	0.81	0.775	74.10	<0.0005*
Lack of smooth pursuit†	0.002	0.962	58.52	<0.0005*
Distinct and sustained nystagmus at maximum deviation†	0.004	0.951	38.23	<0.0005*
Onset of nystagmus prior to 45 degrees†	0.52	0.472	53.68	<0.0005*
Vertical gaze nystagmus†	0.36	0.550	38.62	<0.0005*
Walk-and-turn†	0.023	0.879	34.50	<0.0005*
One-leg stand				
Clues†	0.074	0.786	22.40	<0.0005*
Count‡	11.17 (1, 77.9)	0.001*	2.20 (1, 82.5)	0.142
Romberg balance				
Sway†	2.00	0.157	10.61	0.001*
Tremor†	2.43	0.119	0.12	0.734
Time‡	1.46 (1, 85.0)	0.230	3.97 (1, 89.7)	0.049*
Lack of convergence†	0.003	0.957	7.57	0.006*
Vital signs				
Blood pressure				
Systolic‡	1.97 (1, 201.0)	0.162	0.66 (1, 203.0)	0.417
Diastolic‡	10.68 (1, 201.0)	0.001*	0.33 (1, 204.9)	0.564
Pulse rate‡	5.36 (1, 201.0)	0.022*	25.90 (1, 203.3)	<0.0005*
Pupil size‡	237.1 (1, 201.0)	<0.0005*	2.45 (1, 204.1)	0.119
Clinical tests				
Endpoint nystagmus†	1.00	0.318	14.02	<0.0005*
Nearpoint of convergence‡	4.43 (1, 201.0)	0.037*	28.40 (1, 204.4)	<0.0005*
Attentional field of view‡	11.83 (1, 201.0)	0.001*	23.90 (1, 207.3)	<0.0005*

†Wald chi-square with one degree of freedom.
‡*F*-value with degrees of freedom in parentheses.
*Significant at $p < 0.05$.

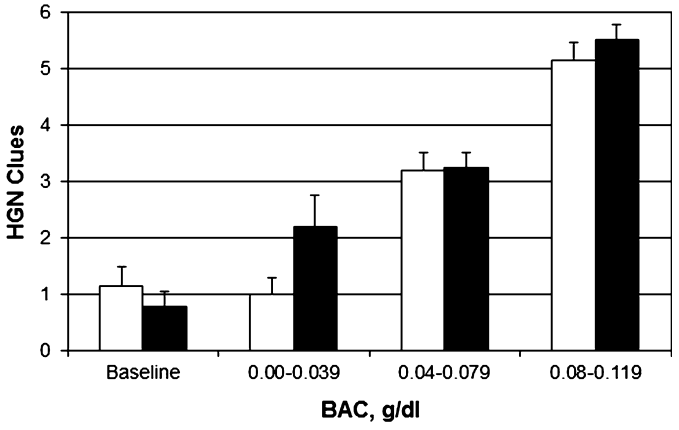


FIG. 2—*Average number of horizontal gaze nystagmus (HGN) clues at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived.*

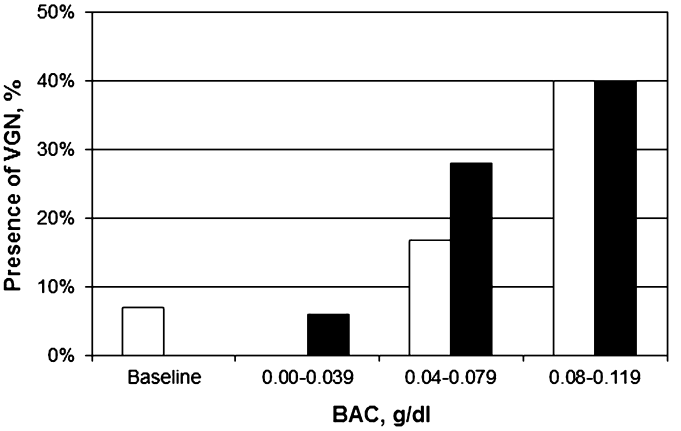


FIG. 3—*Percentage of subjects who exhibited vertical gaze nystagmus (VGN) at baseline and with respect to blood alcohol concentration (BAC). Open bars: normal sleep; filled bars: sleep deprived.*

fatigue resulting from overexertion, exhaustion, or various muscle diseases (64) can do so. Statistical analysis confirms that the average number of tremor clues does not vary significantly with BAC or restedness (see Table 2).

Figure 6*b* shows the average actual time elapsed when subjects estimated the passage of 30 sec. Statistical analysis shows that RB time increases with BAC, from a mean (stdev) of 33.53 (4.68) sec for all baseline measures to 35.52 (4.93) sec for all non-baseline measures. The former average is well within the normal range of 25 to 35 sec (49,57). The latter average is only slightly beyond the maximum time allowed for this test, but not statistically different from it, $t(57) = 0.80$, $p = 0.214$. RB time does not vary significantly with restedness (see Table 2).

Figure 7 shows the percentage of subjects who exhibited LOC. Baseline results indicate that up to about 30% of subjects could not converge their eyes to the bridge of the nose. While this is a better result than expected based on the findings of a normative study (59), it supports the change in procedure to the DRE protocol described above for this test. Statistical analysis shows that the presence of LOC increases with BAC but does not vary significantly with restedness (see Table 2).

Vital Signs

Most subjects exhibited BP and pulse rate measures within or slightly below normal ranges during all test periods, including

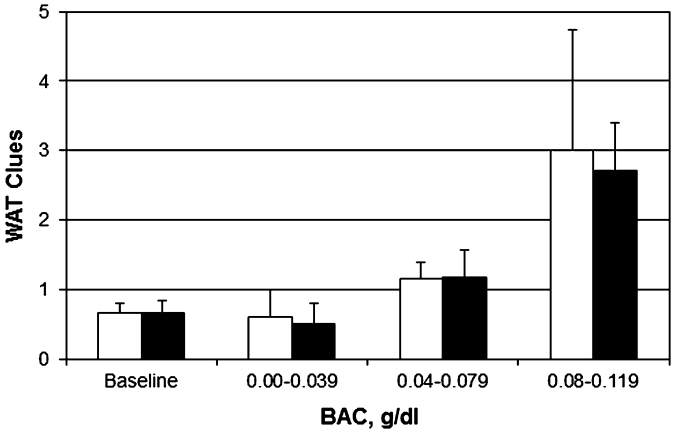


FIG. 4—*Average number of walk-and-turn (WAT) clues at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived.*

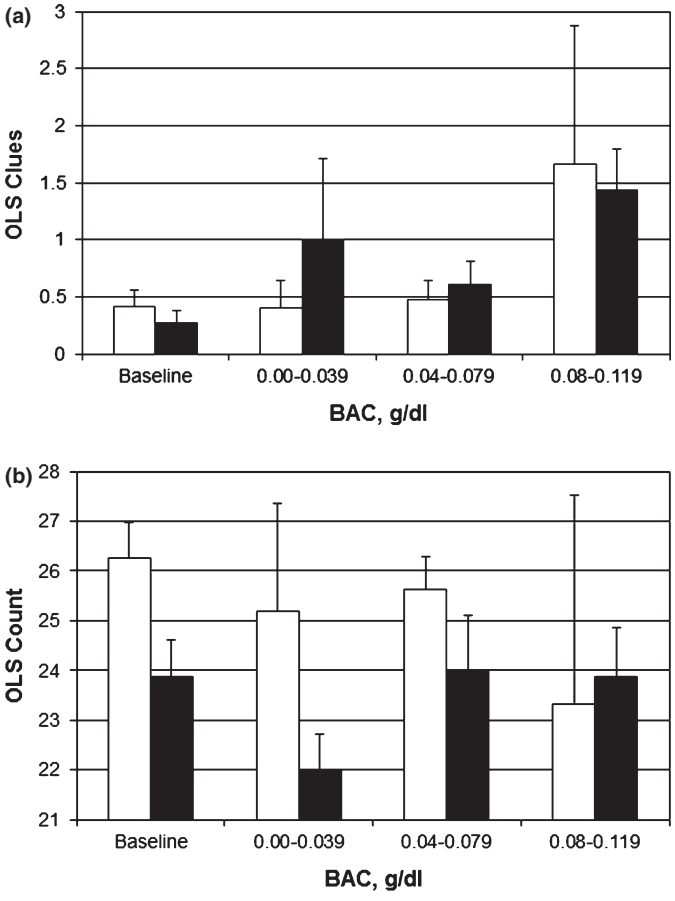
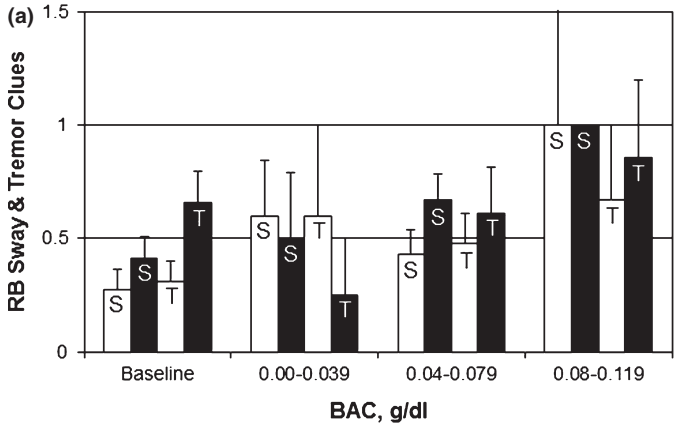


FIG. 5—*Average number of one-leg stand (OLS) (a) clues and (b) count at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived.*



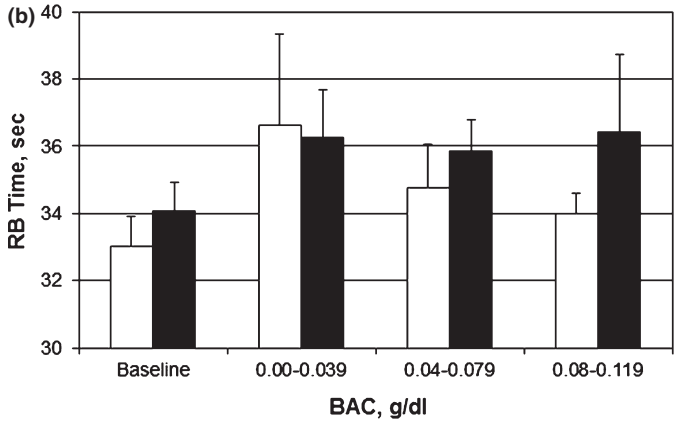


FIG. 6—*(a) Average number of Romberg balance (RB) sway (S) and tremor (T) clues at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived. (b) Average Romberg balance (RB) time estimation of the passage of 30 sec at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived.*

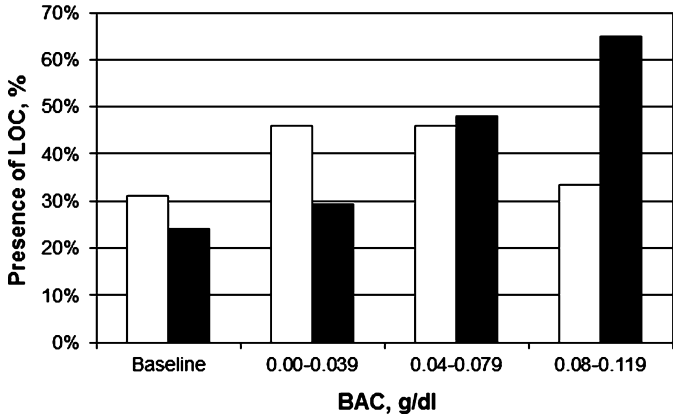


FIG. 7—*Percentage of subjects who exhibited lack of convergence (LOC) at baseline and with respect to blood alcohol concentration (BAC). Open bars: normal sleep; filled bars: sleep deprived.*

overnight and baseline, which is no cause for concern. No abnormal or adverse changes were reported for any subject at any time, even for the subject with known hypertension.

Figure 8 shows the average systolic and diastolic BP. Statistical analyses show that systolic BP does not vary significantly with restedness or BAC, with an overall mean (stdev) of 121.8 (18.9) mmHg, and that diastolic BP increases slightly but significantly with SD, from 75.2 (10.0) to 77.8 (8.7) mmHg, and does not vary significantly with BAC (see Table 2).

Figure 9 shows the average pulse rate. Statistical analysis shows that pulse rate varies significantly with both restedness and BAC

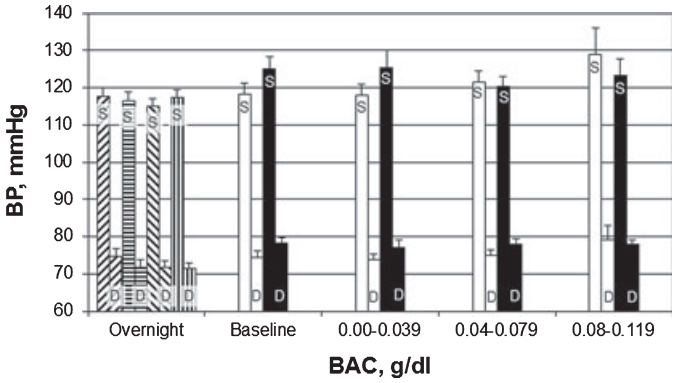


FIG. 8—*Average systolic (S) and diastolic (D) blood pressure (BP), in mmHg, at overnight, baseline, and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Striped bars: four overnight test intervals; open bars: normal sleep; filled bars: sleep deprived.*

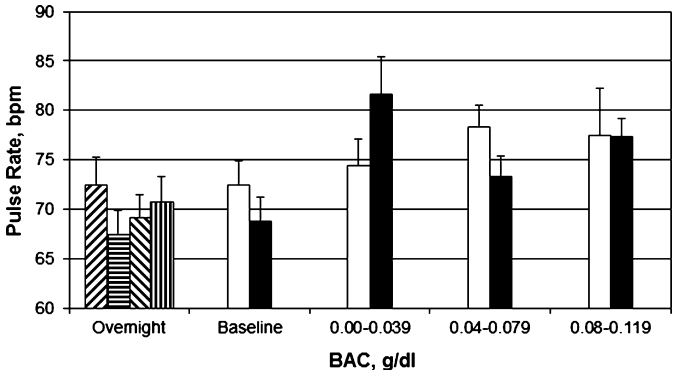


FIG. 9—*Average pulse rate, in bpm, at overnight, baseline, and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Striped bars: four overnight test intervals; open bars: normal sleep; filled bars: sleep deprived.*

(see Table 2), at baseline decreasing from a mean (stdev) of 72.4 (13.2) bpm after normal sleep to 68.8 (13.2) bpm with SD, but increasing during the test periods to overall means of 77.1 (15.2) bpm after normal sleep and 75.9 (13.9) bpm with SD.

Only one subject exhibited anisocoria of 1 mm at a single measure, and only four other subjects exhibited anisocoria of 0.5 mm during any test period, resulting in an overall prevalence of 5 of 29 (17.2%) for this cohort. This is consistent with previous findings for both magnitude and prevalence (65). Consequently, pupil sizes are reported and analyzed only as the average over the two eyes for each subject. Figure 10 shows average pupil size in mm. During the overnight period, most subjects exhibited pupil sizes above the maximum of the normal range for "room light," i.e., 5 mm. At the three measures taken during nighttime hours, all before 7 AM, mean (stdev) was 6.21 (0.76) mm. This is expected, given the relatively low lighting during the overnight periods, and is not a cause for concern. For the fourth measures during the overnight periods, all taken after 8 AM at the higher lighting level noted above, mean (stdev) was 5.66 (0.99) mm. Using a two-tailed paired *t*-test, this is not statistically different than the baseline measure during the actual test session a few hours later under slightly brighter lighting, 5.42 (0.73) mm, $t(56) = 1.02$, $p = 0.312$. For the actual test sessions, statistical analysis shows that overall average pupil sizes consistently are almost 1 mm larger with SD, from 4.47 (0.85) mm to 5.41 (0.73) mm, which is statistically significant (see Table 2). Nonetheless, average pupil sizes do not vary significantly with BAC.

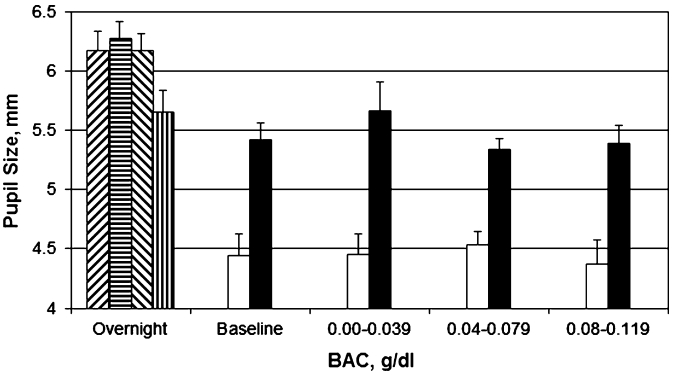


FIG. 10—*Average pupil size, in mm, at overnight, baseline, and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Striped bars: four overnight test intervals; open bars: normal sleep; filled bars: sleep deprived.*

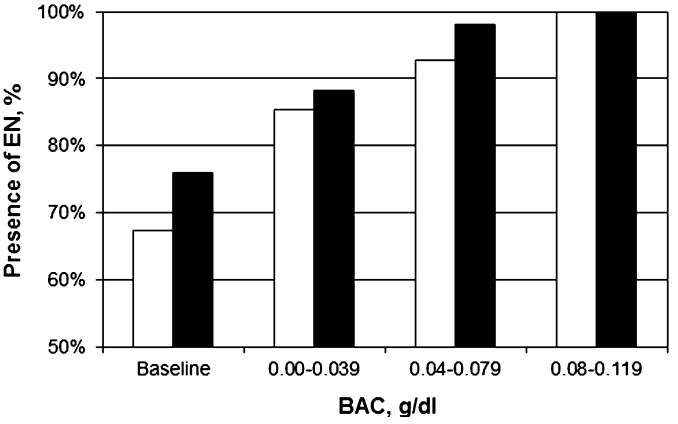


FIG. 11—*Percentage of subjects who exhibited endpoint nystagmus (EN) at baseline and with respect to blood alcohol concentration (BAC). Open bars: normal sleep; filled bars: sleep deprived.*

Clinical Tests

Figure 11 shows the percentage of subjects who exhibited EN. Statistical analysis shows that the presence of EN does not vary significantly with restedness but increases with BAC (see Table 2), from about 70% at baseline, which is only slightly greater than reported elsewhere (60), to 100% at BAC of 0.08 g/dL and above.

Figure 12 shows average NPC. Statistical analysis shows that consistent with previous research, NPC recedes significantly with both SD (66) and BAC (67,68) (see Table 2), from <4 cm on average at baseline to almost 8 cm on average at BAC of 0.08 g/dL and above.

AFOV is calculated as the total field over both eyes. Figure 13 shows average AFOV. Statistical analysis shows that consistent with previous research, AFOV is significantly reduced with both SD (31) and BAC (30,68,69) (see Table 2), from about 94 deg on average at baseline to about 76 deg on average at BAC of 0.08 g/dL and above.

Discussion

The presence and number of impairment clues typically assessed with FSTs by law enforcement officers—HGN, VGN, WAT, OLS, LOC, and RB—do not increase with SD of 24 to 32 h, whereas all but RB tremor do increase with BAC, as expected. As all subjects

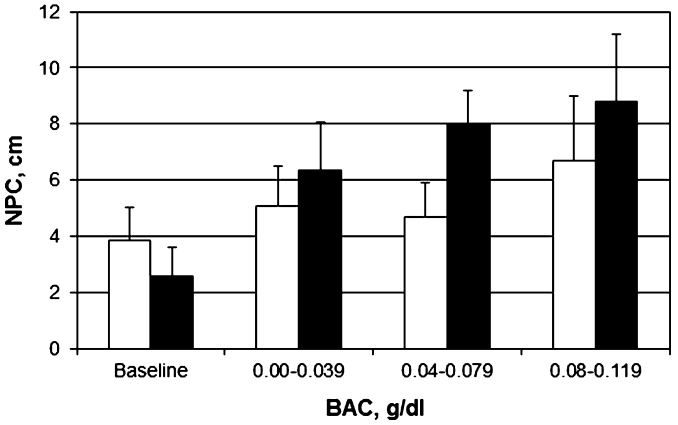


FIG. 12—*Average nearpoint of convergence (NPC), in cm, at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived.*

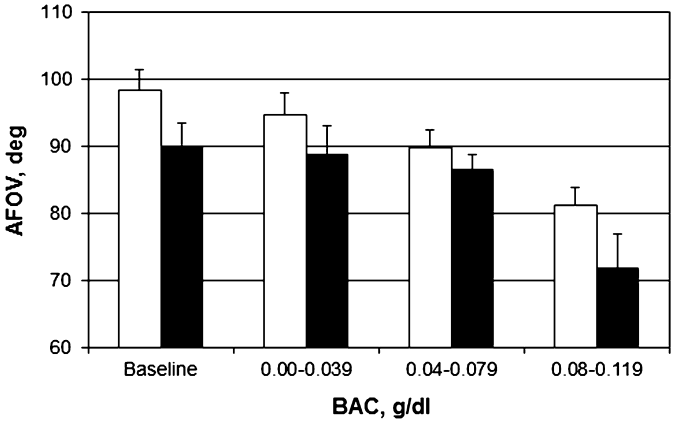


FIG. 13—*Average attentional field of view (AFOV), in deg, at baseline and with respect to blood alcohol concentration (BAC). Standard error bars indicated. Open bars: normal sleep; filled bars: sleep deprived.*

served under both states of restedness, each subject was his or her own control with regard to any potential effects of SD and alcohol intoxication. The separate assertions that SD increases the prevalence of DSNMD (54) and reduces the angle of ONP45 (53), each thereby potentially increasing the number of HGN clues observed, are not substantiated by the current study. The finding that SD exacerbates positional alcohol nystagmus (52) was not evaluated, because officers do not assess this response on impaired drivers (48,49).

A previous report on a single subject (51) and a recent study (42) suggest that SD causes decrements in smooth pursuit eye movements. It is known that 10–20% of a normal population may have problems with smooth pursuits (42,70), depending on the test protocol. However, it is uncertain to what extent such problems would contribute to potential clues exhibited during the LSP subtest. Scientific and clinical testing of patients typically is conducted in an environment and with procedures that are different than those encountered during a traffic stop or drug evaluation. Recordings of eye movements made with specialized instrumentation can identify minute changes in eye position and speed, which likely would not be recognized by mere observation, such as during a clinical screening conducted by a doctor or the LSP subtest conducted by an officer. To wit, Bahill et al. (51) employed nonpredictable target motion, which is not consistent with the stimulus movement during the LSP subtest (48). In addition, Fransson et al. (42) report a decrease in smooth pursuit gain of about 4% only after 36 h of wakefulness and a decrease in smooth pursuit accuracy of about 16% after 24 h of wakefulness, with an improvement in accuracy after 36 h. Neither group of authors drew any conclusions about the HGN test. Interestingly, in the current study, fewer subjects at baseline exhibited LSP when sleep deprived (only three of 29) than after normal sleep (six of 29), which is counter to the implication of the prior research.

The current study also demonstrates that SD does not have a significant effect on the other physiological and psychophysical tasks assessed with the FSTs. The small but significant reduction in OLS count can be attributed to the fact that counting is a cognitive function. Nonetheless, OLS count is not a clue that is considered directly for the evidence of impairment caused by intoxication.

BP and pulse rate are known to increase with varying levels of alcohol consumption (71). The low to moderate levels of alcohol intoxication incorporated within this study had no significant effect on BP but raised pulse rate slightly. The small but significant changes with SD in diastolic BP, pulse rate, and pupil size could be attributed to changes in stress hormone levels (11,72), but not to any caffeine in the beverages most subjects consumed in the morning before the test session (73). Nonetheless, such small changes in vital signs would not raise an officer's suspicion that a suspect could be under the influence of an impairing drug in addition to or other than alcohol (57). We were unable to assess pupil sizes in dim lighting (i.e., near-total-darkness [49]) and pupil reaction to light, both of which are evaluated by clinicians and DREs alike; perhaps future research can address the effects of SD and intoxication on these physiological responses.

Changes in the clinical assessments of EN, NPC, and AFOV with either or both SD and intoxication could assist the clinician to distinguish these conditions from other organic or environmental factors.

For multiple logistical reasons, we could not hold test sessions during late evening or early morning hours, which would have more directly matched the closing times of most establishments that serve alcohol and when many traffic stops occur. However, the times of the test sessions of this study were similar to those used in prior research (18–21,25,26,32–37,39). In general, those studies reached conclusions regarding SD similar or related to those found in studies conducted in the hours around midnight (22–24,27,38). Consequently, even though the precise effects of the subjects' circadian rhythms on the test measures cannot be determined in this study, and especially because everyone's circadian rhythm does not follow the same time course, we do not believe that testing in the hours around midnight would have resulted in any different findings in this study. Future research could investigate this hypothesis.

Conclusion

While SD can affect cognitive ability and certain physiological responses, the results of this study suggest that there is no evidence that it affects eye movements or motor skills assessed with FSTs in a manner that would lead a law enforcement officer to conclude that the suspect is intoxicated, unless intoxication also is present.

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Additional information—reprints not available from author:
Karl Citek, O.D., Ph.D.
Professor of Optometry
Pacific University College of Optometry
2043 College Way
Forest Grove, OR 97116
E-mail: citekk1@pacificu.edu