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Measuring and predicting the effects of alcohol consumption on contrast sensitivity for stationary and moving gratings

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Contrast sensitivity was measured for 12 healthy young males while sober, after ingestion of an alcohol placebo, and after ingestion of alcohol (95% grain alcohol; mean estimated blood alcohol level = .088%). Observations were made for both stationary gratings and gratings that traveled through a circular path and required pursuit eye movements. The significant alcohol-related reduction in contrast sensitivity was 2.6 times greater for moving (.29-log-unit reduction) than for stationary gratings (.11-log-unit reduction). The loss in contrast sensitivity for the moving gratings of high spatial frequency (12 cpd) was particularly severe (.37 log unit). Estimated blood alcohol level was correlated with the loss in contrast sensitivity for moving gratings (r = .61), but not with the loss for stationary gratings. Estimated blood alcohol level was strongly correlated with the difference between the loss in contrast sensitivity to moving and stationary gratings (r = .75). These results are consistent with reports that alcohol consumption degrades the ability to make pursuit eye movements. Subjects' perceived intoxication level was not a reliable predictor of any index of visual performance.

Although a sizable literature addresses the question of whether alcohol affects visual performance (e.g., Adams & Brown, 1975; Adams, Brown, Flom, Jones, & Jampolsky, 1975; Hill & Toffolon, 1990; Miller, 1991; Moskowitz & Sharma, 1974; Sekuler & MacArthur, 1977), the ability to generalize beyond the typical laboratory settings used in this research is limited. Despite recommendations to utilize visual assessment techniques that place greater demands on the observer (National Research Council, 1985), the majority of the studies of the effects of alcohol have relied on standard visual assessment procedures, with static visual acuity being one of the most common measurement techniques. The results of these studies have been mixed, with some studies showing small decreases in acuity after alcohol consumption (e.g., Colson, 1940; Newman & Fletcher, 1941) and others finding no effect (e.g., Adams et al., 1975; Verriest & LaPlasse, 1965).

While much of the literature concentrates on the ability to resolve high-contrast targets, the world outside the laboratory rarely contains such high contrasts (the notable exception being reading materials). Therefore, contrast sensitivity, the ability to discern spatially distinct luminance differences, seems better suited for predicting visual performance. Few studies have addressed the effect of alcohol on contrast sensitivity. Zulauf, Flammer, and Signer (1988) reported that subjects with an estimated blood alcohol level (EBAL) of approximately 0.08% showed a significant decrease (.06 log unit) in contrast sensitivity for sine-wave gratings. Leibowitz et al. (1992), using Vistech VCTS 6500 test charts, found no difference between standing and walking observers' contrast sensitivities after alcohol con-

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sumption (mean EBAL = 0.076%), but they did find a significant overall alcohol-related decrease (.03 log unit) in contrast sensitivity. Hazlett and Allen (1968) report that increasing EBAL (as low as .04%) caused a significant decline in contrast sensitivity.

Another problem that hinders the ability to generalize from experimental findings on visual performance to situations outside of the laboratory is that few studies have addressed possible differences between visual performance in static and in dynamic environments. With target motion added to the testing situation, sensory, motor, and cognitive abilities must be coordinated to produce the accurate smooth pursuit eye movements that are necessary for maintaining gaze stability in dynamic situations. Throughout the development of our species, it is unlikely that situations in which visual performance was critical for survival could have been characterized by a stationary observer viewing a stationary target. Thus, it should be beneficial to understand how visual performance is affected by relative motion between the observer and the stimulus.

The literature addressing contrast sensitivity during smooth pursuit eye movements is sparse. Murphy (1978) stated that two subjects' contrast thresholds to gratings of 5.14 cycles per degree (cpd) "increased modestly" (p. 525) when the grating moved horizontally at 7°/sec. Long and Homolka (1992) have reported that contrast sensitivity for 1, 3.3, and 10 cpd gratings (presented for 200 msec) decreased as horizontal target velocity increased from 0° to 90°/sec. Interestingly, Long and Homolka also described an increase in contrast sensitivity (from stationary levels) for 1-cpd gratings as they moved at 30° or 60°/sec for 600 msec . Finally, Scialfa, Garvey, Tyrrell, and Leibowitz (1992) found that circular target motion (5°, 10°, and 15°/sec) increased contrast sensitivity thresholds, especially for gratings of higher spatial frequencies (12 and 18 cpd). They also reported that older subjects' (*M* = 69 years) thresholds were increased at lower velocities than were the thresholds of younger subjects (*M* = 24 years).

Preliminary results suggested that alcohol affects visual performance in static and dynamic environments differently. In a pilot study, Garvey, Goebel, Tyrrell, and Gish (1988) reported that contrast sensitivity to stationary gratings did not decrease significantly for 4 experienced observers with a mean EBAL of 0.10%. However, when target motion was introduced, the alcohol consumption significantly impaired contrast sensitivity, even when the gratings moved at the slowest speed tested (5° of visual angle per second). This study, however, did not use naive subjects, a double-blind procedure, or a placebo condition.

The purpose of the present study was to investigate the effects of alcohol consumption on contrast sensitivity for stationary and moving gratings in naive subjects, using a double-blind procedure and a placebo condition. A secondary goal was to determine whether objective and subjective measures of intoxication could predict any alcohol-related visual impairments.

METHOD

Subjects

Twelve male subjects were recruited through advertisements in local newspapers; they ranged in age from 21 to 30 years (*M* = 22.9 years).[1] Each received a physical examination and completed the Khavari Alcohol Test (Khavari & Farber, 1978) to quantify their drinking experiences. Each subject was a healthy, moderate drinker (as defined by the Khavari Alcohol Test) with no known visual pathology and a decimal acuity of 1.0 or better at the test distance of 140 cm. Each was naive about the purpose of the study and signed an informed consent form after being briefed about the procedure. After completing the study, each subject was debriefed and paid for his participation (which totaled approximately 12 h).

Apparatus

Contrast sensitivity was determined for sine-wave gratings of 1.5, 6, and 12 cpd, generated by a Picasso image synthesizer (Innisfree) and presented on a Tektronix 608 oscilloscope (P31 phosphor) at a space-averaged luminance of 36 cd/m^2. The face of the oscilloscope was masked with a circular aperture with a diameter of 2.6° at the test distance of 140 cm. The subject binocularly viewed the reflection of the aperture in a circular first-surface mirror mounted on the shaft of a motor (see Figure 1). Grating duration, orientation, contrast, and spatial frequency were controlled by a microcomputer interfaced with the image synthesizer.

To impart movement to the gratings, the mirror was mounted on the shaft of the motor in a nonperpendicular manner so that when the motor was activated, the mirror moved eccentrically and caused the image of the target to travel through a circular path (3.7° in diameter) at a speed of 51.7 rpm.[2] Circular motion affords the independent control of the target velocity and the duration of stimulus presentation. The presentation time was 2 sec, during which the grating traveled through 1.72 revolutions. The grating contrast was set to zero between presentations; luminance remained constant. The location on the path at which the stimulus was first presented varied across trials in a pseudorandom fashion.

The modified binary search (Tyrrell & Owens, 1988) procedure, which uses an adaptive strategy to continually adjust the range of possible contrast values, was used to determine contrast thresholds. This procedure determines precise thresholds with a low sensitivity to response errors and after relatively few stimulus presentations (generally between 12 and 16). The latter quality was particularly important, due to the fact that multiple threshold measurements were required during the limited time period when the EBAL was within the desired range. The procedure was implemented in such a way that eight reversals and a final step size of less than 5% of the 1,273 contrast levels preceded threshold determination. The subject's task was to indicate verbally whether the grating orientation was vertical, tilted 15° clockwise ("right"), or tilted 15° counterclockwise ("left"). In an effort to control for potential criterion shifts, grating orientation was determined randomly for each presentation, and subjects were forced to choose one of the three alternatives.

An Intoximeter 3000 (Intoximeter, Inc.) sampled the alcohol concentration in the subject's expired breath with a measurement error of ±.003%. The subjects also estimated their perceived intoxication level (PIL) by pointing to a number on a scale that ranged from 1 (*cold sober*) to 10 (*drunk*).

Procedure

Each subject participated in each of three counterbalanced alcohol conditions on separate days: *control* (subjects neither expected nor received alcohol); *placebo* (subjects expected alcohol but received only a negligible amount); and *alcohol* (subjects expected and received alcohol). There were, on the average, 6.2 days (range = 1–23 days) between conditions. These conditions al-

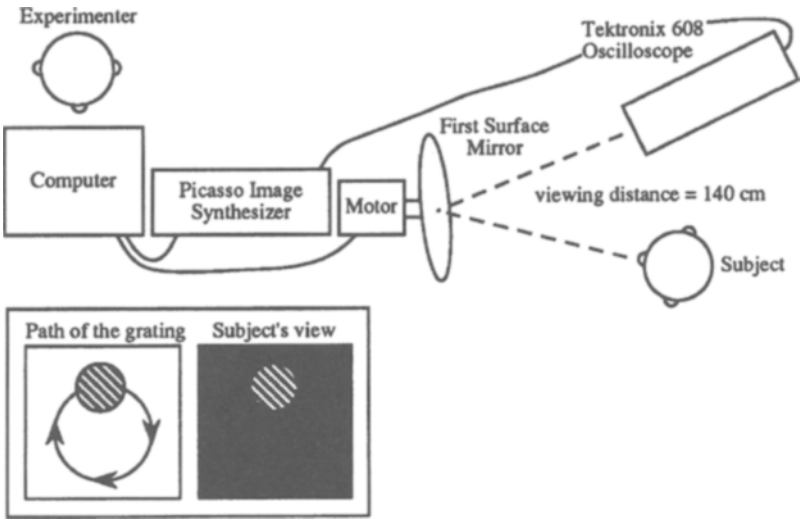

Figure 1. The experimental configuration, indicating the path of the grating and the subject's view.

lowed for differentiation between the physiological effects of alcohol (here defined as the performance difference between the placebo and alcohol conditions) and the psychosocial effects of alcohol (the performance difference between the control and placebo conditions). Although both subject and experimenter knew when the control condition was being tested, neither knew whether the placebo or the alcohol condition was being tested on the two remaining sessions. A registered nurse was present for all alcohol and placebo sessions.

The subjects were asked not to eat or drink anything after 10 p.m. the preceding evening and were instructed not to consume any alcohol or other drugs 24 h before testing. Each subject reported having complied with these restrictions. Upon arriving, the subject was briefed about testing procedures and ate a small breakfast of one piece of toast and 6 ounces of juice. The breakfast was intended to prevent adverse effects from consuming alcohol on an empty stomach and to control stomach content.

In both the placebo and the alcohol conditions, the subject was told that he would receive alcohol. In each of these two sessions, the subject received a mixture of 8 ounces of citrus juice and a dose of alcohol (95% grain alcohol) divided equally into 12 paper cups. The dosage for the alcohol condition was 1.4 ml of alcohol per kilogram of body weight and was intended to raise the subject's EBAL to approximately .10%. In the placebo condition, several drops of alcohol were floated on the top of each cup of juice to provide the taste and smell of alcohol. For both conditions, the subject drank one cup per minute for 12 minutes. After consuming, the subject rinsed his mouth with water and proceeded directly to the testing room. An additional explanation of the procedures was then given, and testing began after a 10-min period of dark adaptation.

During each session, contrast sensitivity was assessed in six blocks of six measurements. Each block consisted of a randomized order of the three spatial frequencies at each of the two speeds (0 and 51.7 rpm). For the measurements with moving gratings, each subject began tracking the aperture prior to the grating presentation. The subject was alerted when a grating was about to be presented. A practice presentation was given at the highest contrast level before each of the 36 measurements. EBAL and PIL were assessed following each block of six measurements (every 10–15 min). When the testing was complete, the nurse remained with the subject in the laboratory until the subject's EBAL reached 0.015%, after which the subject was driven home.

RESULTS

In the alcohol condition, EBAL averaged 0.088% (*SD* = .028%; range = .032–.155%) during the testing period. Perceived intoxication measurements in this condition had a mean of 5.47 (*SD* = 1.93; range = 1–10). During the placebo condition, all EBAL measurements were equal to 0.00%, and perceived intoxication responses averaged 1.96 (*SD* = 1.49; range = 1–8). As illustrated in Figure 2, most of the testing occurred during the ascending portion of the EBAL curve.[3]

After fitting a full repeated measures analysis of variance (ANOVA) model with four factors (subject, condition, speed, and spatial frequency), the nonsignificant terms ($p > .05$) were removed and the reduced model

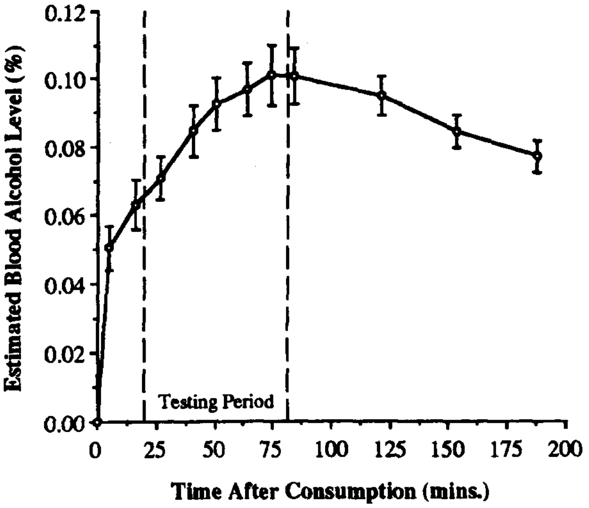

Figure 2. Mean estimated blood alcohol level as a function of time. Error bars represent ±1 *SEM*.

was fitted with the remaining terms. The subject variable was treated as a random effect. No practice effects were found within or among the three conditions. The significant three-way interaction between speed, alcohol condition, and spatial frequency [$F(4,110) = 4.06$, $p < .01$] indicated that the effects of condition and spatial frequency (and their interaction) depended on whether the gratings were stationary or moving. To explore this three-way interaction further, a separate analysis was performed on the interaction between alcohol and spatial frequency at each speed.

The upper graph of Figure 3 presents contrast sensitivity for the stationary gratings as a function of spatial frequency. Here, the total effect of alcohol (control minus alcohol) was significant but relatively small [.11 log unit decrease; $F(2,22) = 19.56$, $p < .0001$]. Tukey's pairwise comparison testing showed that the means for the control, placebo, and alcohol conditions were significantly different from each other ($\alpha = .05$, $df = 22$). The physiological effect of alcohol (an average .06-log-unit decrease) was similar in magnitude to the psychosocial effect (an average .05-log-unit decrease). The magnitudes of these alcohol effects were consistent across the three spatial frequencies (the condition × spatial frequency interaction was not significant [$F(4,44) = .80$, $p = .53$].

With moving gratings (Figure 3, lower graph), the alcohol-related losses were much larger [a .29-log-unit decrease; $F(2,22) = 40.46$, $p < .0001$] and spatial frequency dependent [condition × spatial frequency interaction: $F(4,44) = 4.14$, $p < .01$]. Here, the physiological effect of alcohol (an average decrement of .27 log unit) was significant (Tukey's test, $\alpha = .05$, $df = 22$) and an average of 13.5 times greater than the psychosocial effect (an average decrease of .02 log unit; Tukey's test, $\alpha = .05$, $df = 22$, $p =$ n.s.), with larger losses associated with higher spatial frequencies. These losses are substantial. The total effect of alcohol was to decrease contrast sensitivity to moving gratings by 0.29 log unit, approximately corresponding to a doubling of the contrast necessary to reach threshold. The total loss in sensitivity to moving 12-cpd gratings was even greater (0.37 log unit).

To examine the relationship between objective and subjective estimates of intoxication and visual performance, each subject's overall mean EBAL and PIL were calculated. Each mean was defined as the average of the EBAL and PIL assessments that were recorded immediately before the first and after each of the six blocks of contrast sensitivity measurements. Mean EBAL was not significantly correlated with mean PIL [$r(11) = -.22$, $p =$ n.s.]. In addition, the time courses of the two measures were different: the mean EBAL increased as the experiment progressed, but the mean PIL decreased (Figure 4). This inverse relationship is similar to the findings of Lukas, Mendelson, and Benedikt (1986), who found that perceived intoxication ratings begin to decline sooner than plasma alcohol levels. Thus, there was no systematic relationship between objective and subjective estimates of intoxication. Given this independence, the next step was to establish whether either of these variables could predict the loss in visual performance that accompanied alcohol consumption.

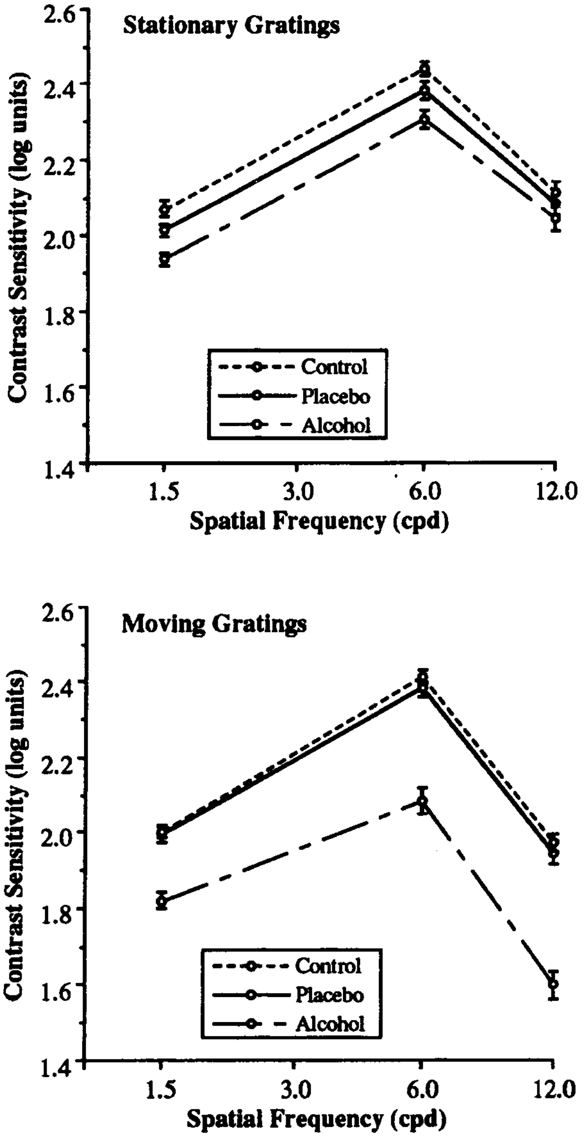

Figure 3. Contrast sensitivity as a function of spatial frequency for stationary and moving gratings for each of the three conditions. Error bars represent ±1 *SEM*.

To index each subject's total alcohol-related loss in contrast sensitivity, each subject's mean contrast sensitivity from the alcohol condition was subtracted from the mean contrast sensitivity from the control condition. This index was computed separately for stationary and moving gratings. The mean loss in contrast sensitivity for stationary gratings was not correlated with the mean loss in contrast sensitivity for moving gratings [$r(11) = .09$, $p =$ n.s.]. Thus, knowledge of the magnitude of the effect of alcohol consumption on contrast sensitivity for stationary gratings could not be used to predict the loss in contrast sensitivity for moving gratings.

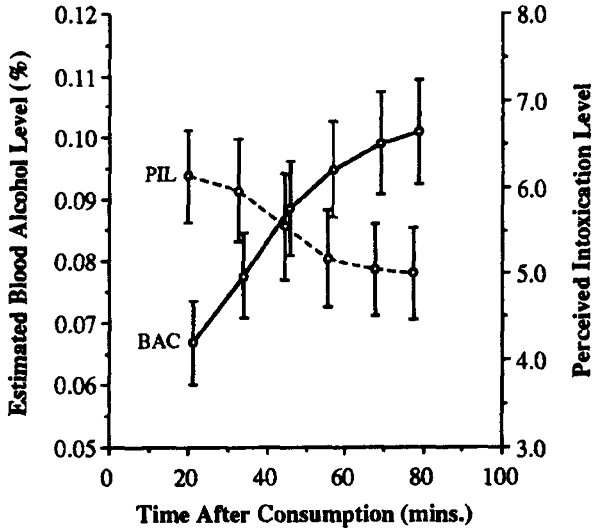

Figure 4. Estimated blood alcohol level and perceived intoxication level (PIL) as a function of time. PIL function is displaced to the left slightly for clarity. Error bars represent ±1 *SEM*.

As shown in Figure 5 (upper graph), mean EBAL was not correlated with the mean loss in contrast sensitivity for stationary gratings [$r(11) = -.41, p =$ n.s.]. There was, however, a moderately strong relationship between mean EBAL and the loss in contrast sensitivity for moving gratings [$r(11) = .61, p < .05$]. Although EBAL explains only 37% of the variability in the loss in sensitivity to moving gratings, these losses did tend to be greater for subjects with a higher mean EBAL (Figure 5; lower graph). Mean PIL was not correlated with the mean loss in contrast sensitivity for stationary gratings [$r(11) = -.06, p =$ n.s.] or moving gratings [$r(11) = -.13, p =$ n.s.], indicating that measures of perceived intoxication could not predict the alcohol-related loss in visual performance.^{4}

DISCUSSION

Alcohol consumption significantly degraded contrast sensitivity. These impairments were most severe for moving gratings of high spatial frequency. Objective estimates of intoxication (EBAL) were correlated with the alcohol-related loss in contrast sensitivity for moving gratings, but not stationary ones. Subjective estimates of intoxication (PIL) were not related to these impairments. These two measures of intoxication were also unrelated.

Unlike the loss for moving gratings which increased as spatial frequency increased, the alcohol-related loss in sensitivity for stationary gratings was similar across all measured spatial frequencies. The alcohol-related loss in contrast sensitivity to moving gratings (.29 log unit) is similar in magnitude to the difference in contrast sensitivity that Owsley, Sekuler, and Siemsen (1983) found between subjects in their twenties and subjects in their sixties. The larger loss in contrast sensitivity for moving gratings at 12 cpd was more severe (.37 log unit) and is similar to the decrement reported by Garvey et al. (1988).

The greater alcohol-related loss to moving gratings of 12 cpd is consistent with the hypothesis that inadequate pursuit movements produced retinal smear (Ludvigh & Miller, 1958), but this remains to be tested empirically. Murphy (1978), however, did not find a strong relationship between retinal image speed and pattern visibility when stimuli moved at 7°/sec. It is possible that the effort to make pursuit eye movements interferes with the processing of spatial information independently of pursuit accuracy.

The fact that EBAL was related to the alcohol-related decrement in contrast sensitivity for moving but not stationary gratings is also consistent with the hypothesis that these losses were the result of a degradation in pursuit ability. Additional evidence supporting this hypoth-

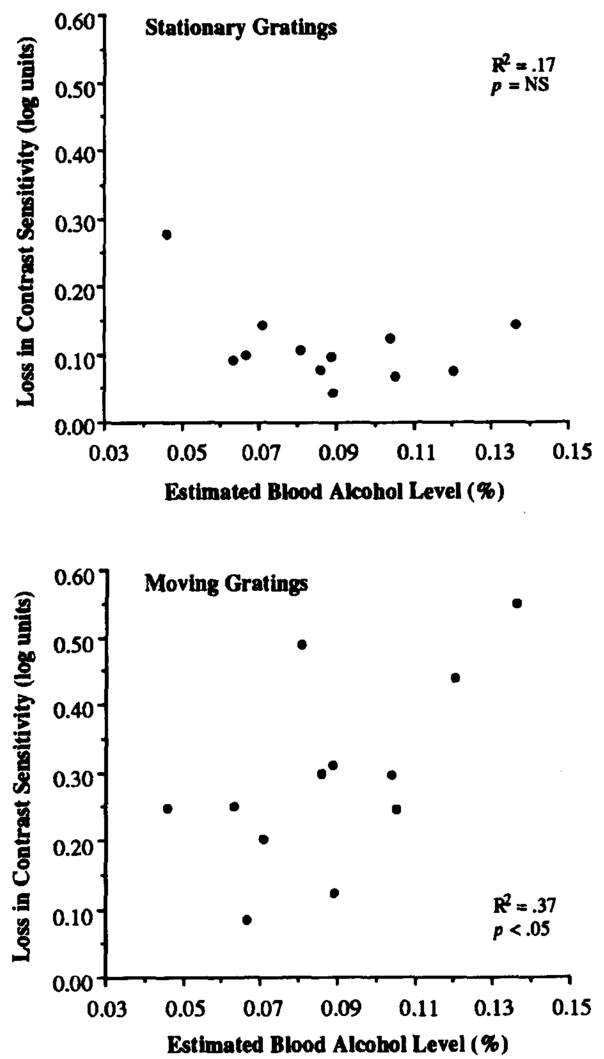

Figure 5. Total (physiological and psychosocial) loss in contrast sensitivity as a function of estimated blood alcohol level for stationary and moving gratings.

esis was the relationship of EBAL to the difference between the alcohol-related losses in contrast sensitivity for stationary and for moving gratings. This difference was calculated for each subject by subtracting the mean loss in contrast sensitivity for stationary gratings from the mean loss in contrast sensitivity for moving gratings. As Figure 6 shows, this difference did increase as EBAL increased [$r(11) = .75, p < .01$].[5] This is consistent with the evidence that indicates that alcohol consumption degrades the ability to execute accurate pursuit eye movements (e.g., Baloh, Sharma, Moskowitz, & Griffith, 1979; Flom, Brown, Adams, & Jones, 1976; Guedry, Gilson, Schroeder, & Collins, 1975; Wilkinson, Kime, & Purnell, 1974).

The impairment induced by alcohol consumption was 2.6 times greater when the grating was moving than when it was stationary. Thus, thresholds measured during static viewing can underestimate the effect of alcohol consumption on the ability to see in other conditions. It is possible that the addition of smooth pursuit movements to the visual testing environment represents an important added demand that could more accurately reflect the active nature of visual perception outside the laboratory. The fact that alcohol consumption is particularly degrading during a dynamic task suggests a nonnegligible sensorimotor impairment that could have considerable import to extralaboratory situations. Direct tests of this possibility remain to be performed.

The independence of the subjective and objective estimates of intoxication is disconcerting, as is the lack of relationship between a subject's PIL and the loss in contrast sensitivity for moving gratings. Since PIL is most typically the only measure of intoxication available to the drinker, its inability to predict visual performance limits its usefulness. Since a drinker cannot compensate for a loss in visual function for which he/she is not aware, the inability of subjective estimates to predict performance decrements is dangerous. Although EBAL was moderately correlated with the loss in contrast sensitivity for moving gratings, it is not readily available to the drinker. Additional investigations into the relationship between objective and perceived intoxication may provide important insights.

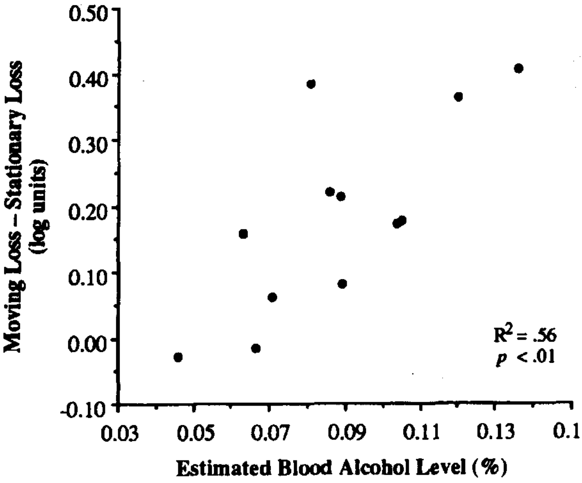

Figure 6. The difference in alcohol-related loss in contrast sensitivity between the stationary and moving conditions as a function of estimated blood alcohol level.

The mean EBAL in this study was below the current legal limit for driving in 45 states. In view of the prevalence of alcohol in traffic accidents (Moskowitz & Robinson, 1988; Ross, 1992) and the relationship between driving performance and dynamic acuity (Burg, 1971), it is important to determine the effect of lower EBAL levels on dynamic contrast sensitivity. It should also be noted that the present study involved only young subjects. In view of the report that pursuit eye movements are degraded in healthy older observers (Sharpe & Sylvester, 1978), and that alcohol has a similar effect (e.g., Wilkinson et al., 1974), investigation of the effects of alcohol on dynamic contrast sensitivity for an older population would also provide valuable data.

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NOTES

1. The sample was limited to males in order to avoid possible complications related to differences in alcohol absorption and metabolism between genders and during different phases of the menstrual cycle (Jones & Jones, 1976), as well as to avoid complications with pregnancies.

2. Motion through a circular path (3.7° in diameter) at a speed of 51.7 rpm is comparable to a linear velocity of 10° of visual angle per second.

3. Mellanby (1919) found motor performance to be worse on the ascending portion of the alcohol absorption curve than on the descending portion. This difference has been validated by several studies (e.g., Nicholson et al., 1992).

4. The loss reported here (the difference between the control and alcohol conditions) represents the total loss (physiological + psychosocial) due to alcohol consumption. The correlations among EBAL, PIL, and the physiological loss in sensitivity to stationary targets and moving targets are as follows:

	Physiological Loss	
	Moving Gratings	Stationary Gratings
EBAL	$r = .65$, $p < .05$	$r = .14$, $p =$ n.s.
PIL	$r = -.01$, $p =$ n.s.	$r = -.27$, $p =$ n.s.
Physiological loss (stationary gratings)	$r = .15$, $p =$ n.s.	

5. PIL was not related to the difference between the alcohol-related losses [$r(11) = -.10, p =$ n.s.].

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