

Alcohol effects on inhibitory control of attention: distinguishing between intentional and automatic mechanisms

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Abstract

Rationale Recent research has begun to explore the possibility that inhibitory mechanisms of selective attention are particularly susceptible to the impairing effects of moderate doses of alcohol. However, literature also suggests that automatic processes might be more resistant to this impairing effect than controlled processes.

Objective The present study used a delayed ocular response task and a saccadic interference task to examine the effects of alcohol on both intentionally controlled and automatic inhibitory influences on selective attention.

Materials and methods Twelve healthy adults performed both tasks under three doses of alcohol (0.0, 0.45, and 0.65 g/kg).

Results The results showed that alcohol reduced intentional inhibitory control over selective attention but had no effect on automatic inhibitory influences.

Conclusion The present investigation marks the first effort to directly compare alcohol effects on automatic and intentional inhibitory mechanisms of visual attention. The results suggest that attentional processes dependent on intentional inhibitory control may be more susceptible to the impairing effects of a moderate dose of alcohol than processes dependent on automatic inhibition.

Keywords Alcohol · Inhibition · Attention · Eye movements · Delayed ocular response task · Saccadic interference task · Controlled processes · Automatic processes

The detrimental effects of acute alcohol consumption on human behavior have been studied extensively in laboratory research (Carpenter 1962; Koelega 1995). Among its many behavioral effects, alcohol is commonly associated with acute states of behavioral disinhibition or dyscontrol that are characterized by impulsive and extreme actions (Jellinek 1952; Lyvers 2000). Research in cognitive neuroscience has focused on the processes that govern behavioral inhibition, suggesting that impairment in this system underlies many deficits of self-control (for reviews, see Arbuthnott 1995; Logan 1994). Model-based assessments of behavioral inhibition mechanisms have been used to study the acute effects of alcohol on the ability to inhibit inappropriate behavioral responses (Fillmore 2003). Several studies have examined alcohol effects using stop-signal and cued go/no-go models that assess behavioral control as the ability to quickly activate and suddenly inhibit prepotent responses (Abroms et al. 2003; de Wit et al. 2000; Fillmore and Vogel-Sprott 1999; Marczinski and Fillmore 2003; Mulvihill et al. 1997). These studies found that moderate doses of alcohol impaired the ability to inhibit a prepotent response. Together, the evidence suggests that the impulsivity and under-controlled behaviors associated with alcohol use could be due, in large part, to an acute impairment of inhibitory control over prepotent behavioral actions (Fillmore 2003).

The impairing effects of alcohol on attention are also well documented (Koelega 1995). Alcohol disrupts performance on divided attention tasks that require simultaneously attending to two or more activities, as well as vigilance tasks that require prolonged attention to changing stimuli (e.g., Fillmore et al. 1998; Michel and Battig 1989). The nature of this impairment is not well understood, but there is some reason to also suspect impairments of inhibitory mechanisms.

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Inhibitory mechanisms have been implicated in selective attention, especially in contexts in which cognitive resources are to be directed toward relevant stimuli (or attributes of stimuli) and away from irrelevant stimuli (or attributes of stimuli). Evidence from laboratory models of selective attention suggests that irrelevant information is inhibited with an active gating mechanism that allows relevant information to be processed with minimal interference (Fox 1995; Houghton and Tipper 1994; Klein 2000; May et al. 1995). In *negative priming*, subjects display increased response time to attributes that were recently ignored as being irrelevant, because of residual inhibition (Houghton and Tipper 1994). There is some evidence that alcohol affects inhibition associated with negative priming: alcohol reduces the time cost normally associated with responding to recently ignored stimuli, suggesting that the drug impairs the normal inhibitory mechanism that directs attention away from irrelevant information (Abroms and Fillmore 2004; Fillmore et al. 2000a,b).

Although recent studies on alcohol and attention highlight the importance of inhibitory mechanisms, there remain many questions concerning the specific nature of the inhibitory mechanisms impaired by alcohol. A fundamental distinction among inhibitory mechanisms concerns whether the mechanism is intentionally controlled or is automatic (Marzi 1999; Shimojo et al. 1999). Intentional inhibitory mechanisms are under the control of the individual, and operate at the level of awareness (e.g., trying not to look). By contrast, automatic inhibitory mechanisms occur without intention in a reflexive manner evoked by the presence of irrelevant stimuli.

Previous reviews of alcohol's effect on attention have indicated that both automatic and intentional inhibitory mechanisms of attention can be impaired under moderate doses of alcohol (Holloway 1995). On the other hand, alcohol studies on skilled behaviors suggest that actions governed by controlled, intentional mechanisms might be more vulnerable to the impairing effects of moderate alcohol doses (i.e., blood alcohol concentrations <100 mg/100 ml) compared with behaviors that are predominantly under automatic influences (Fillmore and Vogel-Sprott 2006; Holloway 1995). However, to date, very few studies have compared the effect of moderate doses of alcohol on automatic and intentional inhibitory mechanisms of attention.

The present study tested the possibility that alcohol-induced impairment of inhibitory mechanisms of attention differed depending on whether the inhibitory mechanism was automatic or intentional. A group of healthy young adults performed two different selective attention tasks: a saccadic interference (SI) task and a delayed ocular response (DOR) task. The two tasks were similar in that each required the subject to execute a saccade (eye

movement) along a horizontal path to a target stimulus. However, the tasks differed in the inhibitory mechanism implicated. The SI task measures an automatically occurring inhibitory mechanism of selective attention. The SI task presents a distractor stimulus, as the subject executes a saccade to the target, which automatically evokes inhibition to reduce the distractor's potential interference on the path and speed of the saccade towards the target. The DOR task measures an intentional inhibitory mechanism by assessing the ability of a subject to intentionally inhibit (i.e., delay) the tendency to make a reflexive saccade toward the sudden appearance of a visual stimulus. The effect of alcohol on the performance of each task was examined in response to three doses (0.0, 0.45, and 0.65 g/kg) that were administered during separate days and in a random dose order across subjects.

Subjects' selective attention in these tasks was measured by the subjects' ocular fixations and movements during task performance. Eye movements are indicative of shifts of visual attention, as both share the common goal of selecting relevant portions of the visual environment (e.g., Hyona et al. 2003; Godijn and Theeuwes 2003). In fact, several theories have proposed a very tight relationship between the movements of the eye and attention (e.g., Posner 1980), and several experiments have shown that attention shifts almost always precede saccades to the attended area (refer to Godijn and Theeuwes 2003).

Materials and methods

Participants

Twelve participants (six men and six women) between the ages of 21 and 28 years (mean age=23.3 years, SD=2.5) participated in the study. All subjects identified themselves as Caucasian. They completed questionnaires that provided demographic information, drinking habits, and physical and mental health status. Individuals with a self-reported psychiatric disorder, substance abuse disorder, head trauma, or other CNS injury were excluded from the study. Subjects with a score of 5 or higher on the Short-Michigan Alcoholism Screening Test (S-MAST) (Selzer et al. 1975) were also excluded from the study. No female volunteers who were pregnant or breast feeding participated in the research, as determined by self-report and urine analysis. All participants were screened for recent use of benzodiazepines, barbiturates, and opiates by means of urine analysis. Any volunteer who tested positive for the presence of any of these drugs was excluded from the study. Subjects were recruited via notices posted on community bulletin boards, by word of mouth, and by a classified newspaper advertisement. All volunteers provided informed consent

before participating. The study was approved by the University of Kentucky Medical Institutional Review Board. Volunteers received \$100 for their participation.

Apparatus and materials

The selective attention tasks were operated using E-prime experiment generation software (Schneider et al. 2002) and performed on a personal computer. A chin rest was used to stabilize head movement and maintain a constant eye-to-screen distance of 73.7 cm. Saccades were recorded using a Model 504 Eye Tracking System (Applied Science Laboratory, Boston, MA, USA). Eye locations were sampled at 60 Hz and given *X/Y* coordinates. These coordinates were used to define fixations and saccades. The distance of a saccade and its duration was calculated using fixation onset and offset times. Onsets of fixations were defined as periods of at least 100 ms in which the line of gaze had a standard deviation of less than 0.5° of visual angle. Offsets of fixations were determined by periods of at least 50 ms in which the gaze position was at least 1° of visual angle away from the initial fixation position. The final fixation position was the average of all data sampled between the beginning and end of the fixation.

The delayed ocular response (DOR) and saccadic interference (SI) tasks both measure the ability to execute a saccade to a target location. The two tasks were chosen because they were similar in their response requirements, but different in the nature of the inhibitory mechanism implicated (intentional vs automatic).

Delayed Ocular Response (DOR) task This task measured the ability of a subject to intentionally inhibit the tendency to make a reflexive saccade toward the sudden appearance of a visual stimulus on a computer screen (Ross et al. 1994, 2000, 2005). Participants were seated in a darkened room and instructed to maintain focus on a fixation point. While participants attended to the fixation point, a bright target stimulus was presented in the periphery. The onset of such a stimulus in this context normally causes a saccade to be reflexively executed toward the stimulus (Peterson et al. 2004; Theeuwes et al. 1999). However, in the DOR task, subjects are instructed to “delay” looking at this stimulus (i.e., intentionally inhibit the reflexive saccade), and instead maintain their gaze on the fixation point until it disappears.

A trial began with the presentation of a white fixation point (+) with a luminance of 39.6 lux presented against a black background. Participants were instructed to fixate on this point. After 1,500 ms, the target stimulus (a white circle) briefly appeared for 100 ms to the left or to the right of the fixation point. The fixation point then remained alone on the screen for a random “wait” interval (800, 1,000, and

1,200 ms). Participants were to withhold any saccade to the target. After the wait interval, the fixation extinguished and the display was blank for 1,000 ms; the disappearance of the fixation point was the signal for participants to then make a saccade to the location in which the target had appeared as quickly as possible.

A test consisted of 96 trials. Fixation points and targets were presented in five locations that were separated from each other by 4.1° of visual angle. The five positions were located horizontally across the center of the screen, resulting in four possible visual angles between the fixation point and target: 4.1, 8.2, 12.3, and 16.4. Each trial began with the presentation of the fixation point at the target location of the preceding trial. Each of the four angular distances and the direction of the saccade required between the fixation point and target locations were presented on an equal number of trials during a test (24 trials at each angle, 12 in each direction). The three different wait intervals occurred in an equal number of trials (32 trials each). The target locations and wait intervals were presented in a random, unpredictable sequence. A test required 7 min to complete.

Validity of the DOR task as a measure of inhibitory control in selective attention has been demonstrated in other research involving populations known to be deficient in the control of attention, such as schizophrenics and those with ADHD. These individuals display poor attention and typically demonstrate reduced inhibitory control against irrelevant stimulus input (e.g., Beech et al. 1989; Hasher et al. 1991). Studies of DOR task performance show that these individuals demonstrate increased inhibitory failures compared with healthy controls, manifested by a greater number of premature saccades that are executed during the waiting period (Ross et al. 1994, 2000, 2005).

Saccadic Interference (SI) task This task measured the ability of a subject to execute a saccade in the presence of an irrelevant, interfering stimulus (distractor). The SI effect is demonstrated in the laboratory as an increase in time required to execute a saccade to targets on trials with a distractor compared with trials with no distractor (Reingold and Stampe 2002). It is argued that the distractor interferes with the generation of the saccade by compromising its programming in the superior colliculus. Automatic inhibitory processes in the superior colliculus are reflexively executed to suppress this interference (Reingold and Stampe 2002; Dorris and Munoz 1998; Munoz and Istvan 1998; Munoz et al. 2000). Larger SI effects indicate greater slowing in response to distraction (i.e., greater interference; Reingold and Stampe 2004).

The SI task used in the present study required participants to make a single saccade to the location of a target on each trial. A trial began with the presentation of a black

fixation point (+) on a grey screen. The grey screen had a luminance of 11.5 lux. After a variable delay of either 500 or 900 ms, the target stimulus (a black circle) was presented to the right or left of the fixation point. The fixation point and target stimulus remained visible together for 1,000 ms, followed by a 1,000-ms inter-trial interval. Participants were instructed to fixate on the fixation point and make a saccade as quickly as possible to the target stimulus as soon as it was presented.

A distractor was presented in half of the trials. The distractor was a brief increase in illumination (33 ms) that occurred at one of five stimulus onset asynchronies (SOAs) after the onset of the target presentation: 0, 50, 100, 150, or 200 ms. The increased illumination was created by presenting two white bars, with a luminance of 39.6 lux, in the top and bottom third of the display. The SOAs were chosen to maximize interference and were based on previous research that found maximal interference effects when the distractor was presented 100 ms before a saccade execution (Reingold and Stampe 2002). On trials with no distractors, the timing of events was otherwise identical.

A test consisted of 80 trials. The fixation point always occurred in the center of the display. Targets were randomly presented 4.1 or 8.2° of visual angle to the right or left of the fixation point. Targets were presented an equal number of times at all four locations, with half the trials at each location comprising distractor trials. A test required 6 min to complete.

Personal Drinking Habits questionnaire (Vogel-Sprott 1992) This questionnaire yields two measures of a participant's current, typical drinking habits: 1) frequency (the number of drinking occasions per week), and 2) customary dose (milliliter of absolute alcohol per kilogram body weight typically consumed during a single drinking occasion)

Subjective measures The degree of subjective alcohol intoxication was measured by a visual analog scale used in other research (e.g., Fillmore 2001). Participants rated their subjective intoxication in terms of how much they “feel the alcohol” by placing a vertical mark through a 100-mm line, with the left side (0 mm) indicating “not at all,” and the right side (100 mm) indicating “very much.” The millimeter distance was measured by a ruler and scored from 0 to 100. Participants also completed a beverage rating scale to report the perceived alcoholic content of their beverages in terms of bottles of beer containing 5% alcohol. The scale ranged from zero to ten bottles of beer, in 0.5 bottle increments. The scale is useful in determining whether participants who receive a placebo are able to detect that no alcohol had been received (e.g., Fillmore and Vogel-Sprott 2000).

Blood alcohol concentrations (BACs) BACs were determined from breath samples measured by an Intoxilyzer, Model 400 (CMI, Owensboro, KY, USA).

Procedure

Screening Individuals responded to the advertisements by calling the laboratory to participate in a telephone intake-screening interview conducted by a research assistant. Participants were told that the study tested the effects of alcohol on computerized measures of performance. They were excluded from participating if they reported any history of neurological problems (e.g., epilepsy), medical contraindications (e.g., liver cirrhosis), abstinence from alcohol, use of prescription medications, current psychiatric treatment, or treatment for problems with alcohol and/or other drug use. After the telephone interview, interested volunteers made appointments to attend a familiarization session. Participants were required to fast for 4 h, refrain from consuming liquid for 2 h and refrain from consuming any alcohol for 24 h before attending all sessions. All sessions were conducted in the Human Behavioral Pharmacology Laboratory at the Psychology Department and required approximately 4 h to complete. Test sessions were scheduled between 11:00 A.M. and 7:00 P.M. weekdays and weekends. All participants were tested individually.

Familiarization During familiarization, participants provided written informed consent were weighed, after which they completed the questionnaires. Participants also performed a familiarization test on both eye tracking tasks to ensure that they understood the task requirements. A single test to acquaint participants with the task requirements was sufficient. After familiarization, the alcohol test sessions were scheduled. Sessions were separated by a minimum of 24 h and a maximum of 3 days.

Alcohol test sessions Preliminary checks were conducted at the beginning of all test sessions. These checks included a breathalyzer test to verify a zero BAC and a urine analysis to verify that participants had not taken other CNS depressant drugs and were not pregnant.

Task performance was tested under three doses of absolute alcohol: 0.0 (placebo), 0.45, and 0.65 g/kg. Dose administration was double-blinded, and dose-order across sessions was randomized across participants. The 0.65 g/kg dose produced an average peak BAC of 75 mg/100 ml and was chosen based on prior research that showed that response inhibition is reliably impaired at this BAC (e.g., Fillmore and Vogel-Sprott 1999, 2000).

A dose was administered as absolute alcohol divided equally into two drinks containing one part alcohol and

three parts carbonated mix. Participants had 2 min to finish each drink, and the second drink was served 2 min after the first drink. This dosing procedure produces a mean rate of rise in BAC of 1.0 mg/100 ml per minute (Fillmore and Vogel-Sprott 1998). The peak BAC after a 0.65 g/kg dose was expected to occur 65 min after drinking began. Once peak BAC is achieved, it remains at a relatively steady state for approximately 10 min (Fillmore and Vogel-Sprott 1998).

The placebo dose (0.0 g/kg) consisted of a volume of carbonated mix that matched the total volume of the 0.45 g/kg alcohol drink. A small amount (3 ml) of alcohol was floated on the surface of the beverage. It was served in two glasses that were sprayed with an alcohol mist that resembled condensation and provided a strong alcoholic scent as the beverages were consumed. The timing of placebo beverage delivery was identical to the alcohol beverage. Previous research has shown that individuals report that this beverage contains alcohol (e.g., Fillmore and Vogel-Sprott 1998).

Task performance was tested 30 min after drinking began. Thus, testing occurred during the ascending period of the blood alcohol curve in the active dose conditions. Task order was randomized for each participant across test sessions. Under each dose three men and three women performed the DOR task first and the remainder performed the SI task first. Testing on the second task began 40 min after drinking began. The subjective effects and beverage rating scales were completed 60 min post beverage administration. BACs were measured at 20, 40, 60, and 90 min after beverage administration. During the placebo session, participants also provided breath samples at those times ostensibly to measure their BAC. After the test session concluded the participants were allowed to relax in a waiting room within the laboratory. Participants could receive a meal and remained at leisure to read magazines or watch television until their BAC fell below 40 mg/100 ml. Transportation home was provided as needed. Upon completing the final session, participants were paid and debriefed.

Criterion measures in data analyses

Both tasks required one primary saccade per trial. This was the first saccade of each trial that occurred after target stimulus onset and covered at least half the distance to the target location for that particular trial. Thus, 96 primary saccades were required during each test on the DOR task and 80 were required on each test on the SI task.

DOR task Primary saccades on the DOR task were categorized based on when they occurred. They were

classified as either premature (i.e., occurred after target presentation but before fixation point offset), valid (occurred during the 1,000-ms response period), or late (i.e., occurred after the next fixation point appeared, beginning the next trial). On the vast majority of trials (approximately 90%), subjects typically execute valid saccades. However, the principal measure was the number of premature saccades that indicated failures of response inhibition during the wait interval. The number of premature saccades was analyzed by a one-way, within-subjects, repeated measures analysis of variance (ANOVA) of dose (0.0, 0.45, and 0.65 g/kg). It was predicted that alcohol would increase the number of premature saccades in a dose-dependent manner. The number of late saccades was also analyzed by a one-way, within-subjects ANOVA of dose.

Even when a subject has executed a valid saccade under alcohol, it is possible that the drug disrupted the saccade by slowing its speed or by reducing the accuracy with which the saccade localized the position of the target. To examine these possibilities, the RT (response time) and accuracy of valid saccades were measured. RT referred to the time in milliseconds required from fixation offset to the completion of the saccade. Lower RT values represented faster saccades. Accuracy referred to the angular discrepancy between the target position and the landing point of the saccade. The difference between these two locations was measured in terms of degree of absolute deviation. Greater deviation scores indicated poorer accuracy of saccades. Alcohol effects on RT and accuracy were each analyzed by one-way, within-subjects ANOVAs of dose. Simple effect analyses using dependent *t* tests compared each active dose condition to placebo.

SI task Saccadic RT was the primary measure of interest for the SI task and referred to the time (milliseconds) from target onset until the fixation at the target location. The saccadic RTs were averaged separately for distraction and no distraction trials for a test to produce a mean RT score for each condition. The SI effect refers to the degree to which the mean RT is longer in the distraction condition compared with the no-distraction condition. Saccadic RTs were analyzed by a three-dose (0.0, 0.45, and 0.65 g/kg) \times 2 trial-condition (distraction vs no distraction) ANOVA. Any impairing effect of alcohol on inhibitory mechanisms in this model should result in increased SI effects and would be evident by a dose-by-trial-condition interaction on RT.

Gender differences in task performance Although there was no basis for predicting gender differences in task performance, all analyses of dose effects on performance initially included gender as a factor. No significant main effects or interactions involving gender were obtained

($p>0.05$). Thus, all analyses of task performance reported in the **Results** section are collapsed across this factor.

Results

Drinking habits There were no gender differences on any drinking habit measure ($p>0.190$). The entire sample reported a mean (SD) drinking frequency of 1.8 (1.3) times per week, with a mean dose per occasion of 1.2 (0.3) ml/kg. For a person weighing 75 kg, this dose would approximate five bottles of beer containing 5% alcohol per volume.

Blood alcohol concentrations No detectable BACs were observed in response to placebo. The BACs for each active dose for both genders are presented in Table 1. Gender differences in BAC under the two active doses were examined by a 2 (gender) \times 2 (dose) \times 4 (time) mixed-design ANOVA. There was a main effect of gender, $F(1, 10)=5.2$, $p<0.045$, due to higher BACs among the females at every measurement time. However, when gender was compared by t test at each time sampled under the two active doses, the only significant gender difference occurred under 0.65 g/kg at 90 min ($p=0.02$), well after the conclusion of testing. Therefore, the BACs between the genders were not significantly different during the time that testing occurred (30–50 min).

The ANOVA also showed significant main effects of dose, $F(1, 10)=60.8$, $p<0.001$, and time, $F(3, 30)=19.0$, $p<0.001$, owing to the higher BACs as a function of dose and the rise and fall of the BAC across time. There was also a significant dose \times time interaction, $F(3, 30)=7.7$, $p<0.001$, owing to a steeper rise in BAC under the 0.65-g/kg dose.

DOR task performance Figure 1 plots the number of premature saccades under placebo and alcohol on the DOR task. It shows that premature saccades increased in a dose-dependent manner. This observation was confirmed by a three-dose, one-way, within-subjects ANOVA of premature saccades, $F(2, 22)=8.0$, $p=0.003$. Two-tailed post hoc analyses compared premature saccades under the two active alcohol doses to placebo, using dependent t tests. In accord with the hypothesis, there was a significant increase

in premature saccades under 0.45 g/kg of alcohol, $t(11)=2.8$, $p=0.017$, and under 0.65 g/kg of alcohol, $t(11)=3.4$, $p=0.006$, compared with placebo.

The effect of alcohol on the number of late saccades was analyzed by a three-dose, one-way, within-subjects ANOVA. No significant effect was observed, $F(2, 22)=1.3$, $p=0.301$. Late saccades were infrequent, and participants rarely executed more than one or two late saccades per test, regardless of dose condition. The mean (SD) number of late saccades under 0.0, 0.45, and 0.65 g/kg alcohol was 0.9 (2.10), 0.9 (4.14), and 1.5 (2.53), respectively.

The RT of valid saccades is shown in Fig. 2. Compared with placebo, RT decreased slightly under 0.45 g/kg alcohol, but slowed in response to 0.65 g/kg alcohol. A one-way, within-subjects ANOVA of RT showed a significant effect of dose, $F(2, 22)=14.7$, $p<0.001$. Two-tailed, post hoc t tests compared RT under the active doses to placebo. There was no significant difference between 0.45 g/kg alcohol and placebo, $t(11)=0.8$, $p=0.431$. However, 0.65 g/kg alcohol significantly increased (i.e., slowed) RT compared to placebo, $t(11)=3.7$, $p=0.003$.

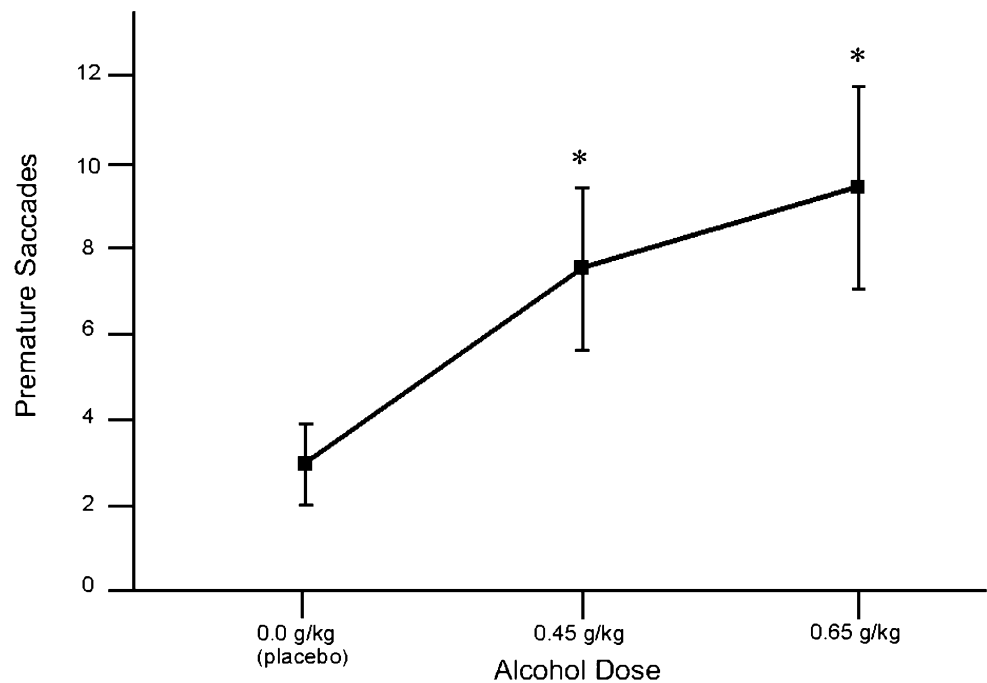
The accuracy of the valid saccades under each dose is plotted in Fig. 3. The figure shows that the deviation between saccade destinations and target locations increased under active alcohol doses, indicating reduced accuracy under alcohol. A one-way, within-subjects ANOVA of dose effects on the degree deviation scores confirmed this observation, $F(2, 22)=6.2$, $p=0.008$. Two-tailed, post hoc t tests compared the mean deviation score under placebo to the active dose conditions and found that deviation was significantly increased in response to both active doses ($ps<0.020$).

SI task performance Figure 4 shows the saccadic RT in the distraction and no-distraction condition across doses. The figure shows that saccadic RTs were slower in the distraction condition and thus confirmed the predicted saccadic interference effect. A three-dose \times 2 trial-condition ANOVA revealed a significant effect of trial condition, $F(1, 12)=34.4$, $p<0.001$. There was no main effect of dose, $F(2, 22)=0.9$, $p=0.413$, or a dose \times trial condition interaction, $F(2, 22)=2.9$, $p=0.075$.

Table 1 Mean (SD) BACs (mg/100 ml of blood) under 0.45 and 0.65 g/kg alcohol in male and female participants

| Dose (g/kg) | Gender | Minutes after beverage administration | | | |
|-------------|--------|---------------------------------------|-------------|-------------|------------|
| | | 20 | 40 | 60 | 90 |
| 0.45 | Male | 47.3 (15.6) | 59.5 (12.3) | 56.8 (7.1) | 39.2 (5.4) |
| | Female | 65.8 (14.6) | 64.5 (8.5) | 58.0 (5.8) | 45.8 (5.8) |
| 0.65 | Male | 63.3 (10.0) | 85.0 (9.5) | 78.3 (9.0) | 61.5 (9.1) |
| | Female | 74.5 (20.7) | 95.3 (18.7) | 90.0 (12.2) | 75.8 (9.0) |

Fig. 1 Mean number of premature saccades during DOR task performance in response to 0.0, 0.45, and 0.65 g/kg alcohol. Asterisk indicates a significant difference from placebo ($p < 0.05$)



Subjective intoxication One-way, within-subjects ANOVAs obtained significant dose effects on subjective intoxication, $F(2, 22)=58.1$, $p < 0.001$, and beverage rating, $F(2, 22)=52.6$, $p < 0.001$. At 60 min after beverage administration, mean (SD) ratings of subjective intoxication were 3.4 (4.1), 27.9 (19.7), and 54.8 (20.0) under 0.0, 0.45, and 0.65 g/kg of alcohol, respectively. Mean (SD) perceived alcoholic content of the consumed drinks was 1.3 (1.1), 3.7 (1.2), and

5.4 (1.4) standard drinks 60 min after consuming 0.0, 0.45, and 0.65 g/kg of alcohol, respectively.

Discussion

This study examined the effects of alcohol on the performance of two selective attention tasks designed to

Fig. 2 Saccadic RT (ms) for valid saccades during DOR task performance in response to 0.0, 0.45, and 0.65 g/kg alcohol. Asterisk indicates a significant difference from placebo ($p < 0.05$)

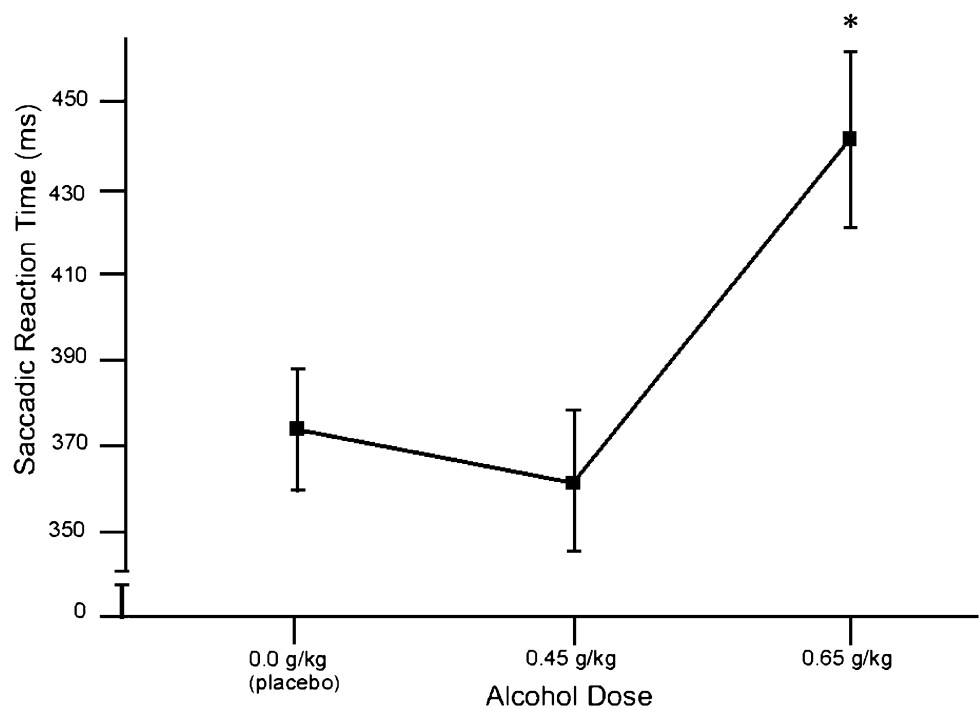
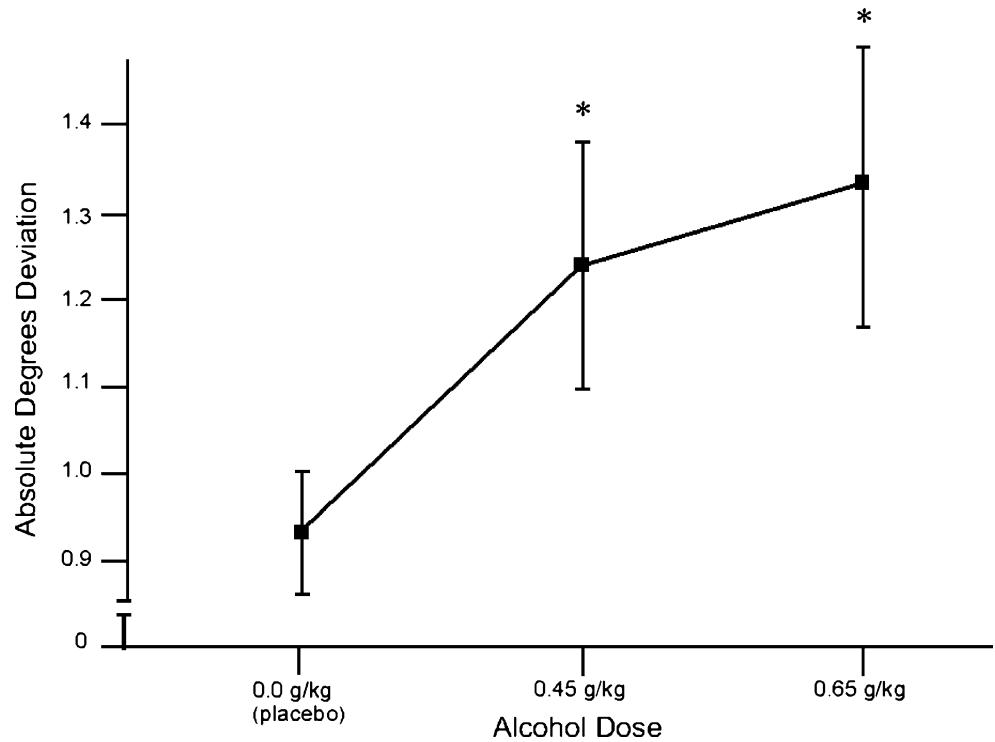


Fig. 3 Accuracy of valid saccades during DOR task performance in response to 0.0, 0.45, and 0.65 g/kg alcohol. Accuracy scores are expressed as absolute degrees deviation from the target location. *Asterisk* indicates a significant difference from placebo ($p < 0.05$)

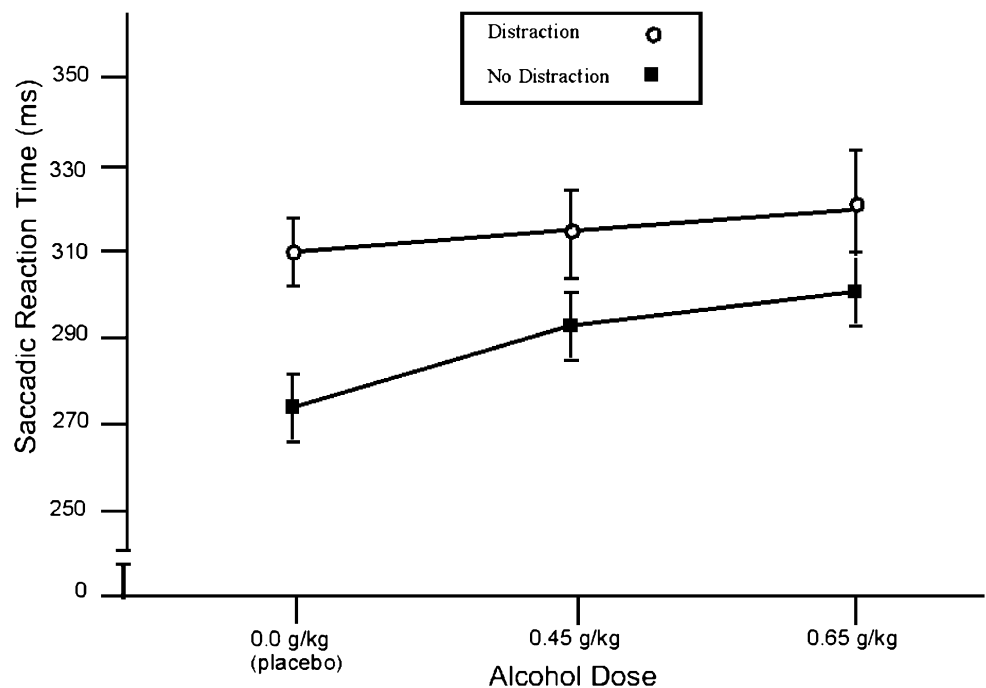


measure the intentional and automatic inhibition of distracting information. The tasks were similar in terms of the response required, but differed in the type of inhibitory mechanism under investigation. The DOR task measured the ability to intentionally inhibit reflexive saccades to the sudden appearance of a visual stimulus. The SI task measured an automatic inhibitory influence that resolved interference produced by an irrelevant visual distraction.

The results showed that moderate doses of alcohol impaired the intentional inhibitory mechanism, but not the automatic mechanism. Participants also reported dose-dependent increases in subjective intoxication and perceived alcohol content of the drinks consumed.

The nature of the inhibitory mechanisms required by each task may account for the differential effect of alcohol on performance. The tasks were similar in many other

Fig. 4 Saccadic RT (ms) on distractor and no distractor trials of the SI task in response to 0.0, 0.45, and 0.65 g/kg alcohol



respects. For example, both tasks required subjects to ignore an irrelevant visual distraction and make a single speeded saccade to a target location. BACs and other experimental factors are also unlikely to contribute to the task differences observed in response to alcohol. The same subjects performed both tasks at comparable BACs during the ascending portion of the BAC curve under active doses and task order was counterbalanced across subjects and dose condition.

Alcohol-induced impairment of intentional inhibition was evident by a dose-dependent increase in premature saccades during performance of the DOR task. In accord with an inhibition-based account, the evidence suggests that subjects were less able to intentionally inhibit a reflexive saccade that is normally reflexively elicited by the sudden onset of the target. Moreover, this impairment was quite pronounced. The number of premature saccades under the highest dose (0.65 g/kg) was nearly three times greater than in response to placebo. The increase in premature saccades under the drug was also accompanied by reduced accuracy and increased RT. The results showed that alcohol increased the degree deviation between the target location and the final destination of the primary saccade in a dose-dependent manner. Thus, the drug appeared to reduce the accuracy of eye movements to target locations. The speed of saccades was also slowed by the highest dose of alcohol (0.65 g/kg) compared with placebo. Under the highest dose, saccades took an additional 60 ms to reach their destination. There was no effect of alcohol on the number of late saccades.

In contrast to DOR task performance, the moderate doses of alcohol tested in this study had no effect on the performance of the SI task. The SI effect was reliably observed in the study on each of the test sessions. As predicted, saccadic RTs in the distraction condition were slower than those in the no-distraction condition, thus replicating the SI effect observed in previous studies that used this model of selective attention (Reingold and Stampe 2002). However, we found no evidence that this interference effect was augmented by the moderate doses of alcohol used in this experiment. The findings showed no change in the magnitude of the SI effect over doses. Moreover, there was no significant change in the general speed of saccades as a function of dose in either trial condition.

Analyses of saccadic RTs showed that only saccades in the DOR task were slowed by alcohol, whereas alcohol had no effect on the speed of saccades in the SI task. This difference may be explained by the types of saccades required by each task: Saccades in the DOR task are intentionally executed or endogenous, whereas saccades in the SI task are automatically elicited or exogenous (Findlay 1997; Godijn and Theeuwes 2003; Theeuwes 1991; Theeuwes et al. 2000; Yantis and Jonides 1990). Eye

movement research has indicated that endogenous and exogenous saccades rely on different neural pathways. Endogenous saccades depend on cortical input to consciously determine when and where to make saccades, while exogenous saccades depend on lower level visual input to reflexively guide the visual system to areas that may contain pertinent information (for reviews, see Hall and Moschovakis 2004; Hyona et al. 2003). The present results suggest that endogenous saccades may be more vulnerable to the impairing effects of a moderate dose of alcohol than saccades that are more exogenous in nature.

One limitation that concerns most measures of visual attention that rely on eye movements is that the processes are not perfectly correlated. While the eyes may be the best indication of where visual attention is being dedicated, there are conditions under which the eyes may be directed to one location while attention is dedicated to a different location. In fact, during DOR task performance, this may occur. It is likely that attention is automatically directed to the sudden onset of the target, as the onset of such a stimulus in similar contexts has been shown to cause a reflexive shift of attention (Yantis and Jonides 1990). However, saccades occur only when attention remains at the onset location for a sufficient period of time. If the participant can redirect attention back to the fixation point before saccade programming is complete, no saccade will occur (refer to Godijn and Theeuwes 2003). Thus, while the measure from the DOR task cannot rule out that attention was dedicated to the onset location, the task does address the ability to intentionally control visual attention. To the degree that the participant can limit the duration that attention remains at the onset location fewer premature saccades should occur.

A fundamental distinction in cognitive science has been made between automatic and controlled influences on behavioral expression. Previous research has shown that behaviors that depend on intentional control might be more vulnerable to the impairing effects of alcohol than behaviors dependent upon automatic processes, suggesting this distinction might be important for alcohol research (Fillmore and Vogel-Sprott 2006; Holloway 1995). The present results show that this distinction might also be relevant for determining which processes are responsible for alcohol-induced impairments of attention-based activities. Although it is likely that automatic inhibitory mechanisms of attention would also be impaired by higher alcohol doses, the present finding, based on moderate doses, suggests that attention-based activities that rely more on intentional processes for control might be more sensitive to alcohol-induced impairment compared with those that rely on automatic processes. The distinction between behaviors dependent on automatic and controlled processes also might be valuable in understanding the effects of other

drugs. Other CNS depressant drugs and CNS stimulants, which also affect attention, might also have differential effects on attention-based activities depending on the involvement of automatic and controlled mechanisms in the selection of attention. Of particular interest are the well-documented facilitating effects of psychostimulants on selective attention and the possibility that such facilitation depends on the degree to which ignoring distraction depends on automatic or intentional inhibitory mechanisms.

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