

# Clubgoers and Their Trendy Cocktails: Implications of Mixing Caffeine Into Alcohol on Information Processing and Subjective Reports of Intoxication

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Alcoholic drink preferences in college students have made an interesting shift recently, with trends in consumption leaning toward caffeinated alcohol in various forms (e.g., Red Bull and vodka or caffeinated beers such as Anheuser-Busch's B-to-the-E). Despite the dramatic rise in popularity of these beverages, little research has examined the combined effects of alcohol and caffeine, which is problematic for adequately informing the public about the risk or lack thereof of these drinks. The purpose of this study was to directly investigate the acute effects of alcohol and caffeine, alone and in combination, on well-validated measures of cognitive performance and subjective intoxication in social drinkers. Participants ( $N = 12$ ) performed a psychological refractory period task that measured dual-task interference as the prolonged reaction time to complete the 2nd of 2 tasks performed in close temporal sequence. Performance was tested under 2 active doses and 1 placebo dose of caffeine (0.0 mg/kg, 2.0 mg/kg, and 4.0 mg/kg) in combination with 1 active dose and 1 placebo dose of alcohol (0.0 g/kg and 0.65 g/kg). As expected, alcohol impaired task performance by increasing dual-task interference and increasing errors. The coadministration of caffeine counteracted the effects of alcohol on interference but had no effect on the degree to which alcohol increased errors. Subjective measures of intoxication showed that coadministration of caffeine with alcohol reduced participants' perceptions of alcohol intoxication compared with administration of alcohol alone. The results highlight the complexity of drug interactions between alcohol and caffeine.

*Keywords:* alcohol, caffeine, information processing, intoxication, college students

Alcoholic drink preferences in college students have made an interesting shift in the last decade, with clubgoers increasingly drawn to caffeinated alcoholic drinks in various forms. With the national introduction of Red Bull to the United States in 2001, young partygoers became enamored with using the beverage as a mixer for their alcoholic drinks, presumably for the purpose of reducing the depressant effects of alcohol and thus allowing them to party longer. This increased popularity of caffeinated alcoholic beverages among college students was quickly identified by the beverage industry in North America. In 2005, several "energy" beers and malt beverages were introduced, including Anheuser-Busch's B-to-the-E (54 mg caffeine in 6.6% alcohol

by volume), New Century Brewing's Moon Shot (45 mg caffeine in 4.8% alcohol by volume), Labatt's Shok (60 mg caffeine in 6.9% alcohol by volume), and Molson's Kick (55 mg caffeine in 5% alcohol by volume).

Some physicians have warned of the potential health implications of mixing caffeine and alcohol, such as increased risk of dehydration (American Medical Association, 2003). Although the various energy drinks and beers also contain other stimulant compounds, such as taurine, theophylline, theobromine, and ginseng, the health concerns of these drinks have been in relation to the high caffeine content. Caffeine is the common stimulatory compound in all of these beverages. Of interest, the U.S. Food and Drug Administration (FDA) does not regulate the caffeine content of energy drinks, and recent analyses have determined that the caffeine content of these drinks can contain 150%–300% of the amount of caffeine that the FDA allows for cola beverages (McCusker, Goldberger, & Cone, 2006). However, there have been surprisingly few investigations into the presumption that these caffeinated alcohol drinks allow drinkers to consume greater amounts of alcohol because the sedation and behaviorally impairing effects normally associated with the drug are offset by the coconsumption of caffeine (Ferreira, de Mello, Pompeia, & de Souza-Formigoni, 2006). Although to date there has been no published study of North American drinkers' motivations

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for using caffeinated alcoholic drinks, a small survey of college students in Brazil ( $N = 136$ ) examined their motivations for using these drinks (Ferreira, de Mello, & Formigoni, 2004). The authors reported that 76% of the sample indicated regular use of energy drinks in combination with alcohol (mainly whiskey, vodka, or beer). Of those who reported use of caffeinated alcohol, 38% reported that the combination drinks increased happiness, 30% reported euphoria from these drinks, 27% reported uninhibited behavior from these drinks, and 24% reported increased physical vigor. Other reports from Ireland and Germany have implicated these drinks in assaults and automobile accidents, respectively, suggesting that the combination of caffeine and alcohol impairs the ability to correctly assess level of intoxication and the ability to drive more greatly than alcohol intoxication alone (Riesselmann, Rosenbaum, & Schneider, 1996; Tormey & Bruzzi, 2001). Correspondingly, Denmark, France, and Norway have placed bans on the sale of Red Bull, citing health concerns.

Caffeine acts as an adenosine receptor antagonist, with the central nervous system (CNS) stimulatory effects of caffeine largely due to blockage of adenosine A2A receptors that stimulate GABAergic neurons of inhibitory pathways to the dopaminergic reward system of the striatum (Cauli & Morelli, 2005; Mandel, 2002; Nehlig, Daval, & Debry, 1992). In addition, caffeine also acts as a CNS stimulant as it is an indirect agonist of noradrenaline (Lader & Bruce, 1989). Laboratory studies of the behavioral effects of caffeine show that the drug can generally enhance skilled performance by allaying fatigue, increasing vigilance, speeding reaction time (RT), and prolonging effort (for reviews, see Nehlig et al., 1992; Weiss & Laties, 1962). The extent to which the coadministration of caffeine can counteract or functionally antagonize alcohol-induced behavioral impairment also has been studied in the laboratory; however, the findings have been mixed. Some studies have shown that caffeine coadministration can reduce the impairing effects of alcohol on some global performance tasks (Burns & Moskowitz, 1990; Fillmore & Vogel-Sprott, 1999; Franks, Hagedorn, Hensley, Hensley, & Starmer, 1975; Kerr, Sherwood, & Hindmarch, 1991; Martin & Garfield, 2006; Rush, Higgins, Hughes, Bickel, & Wiegner, 1993). However, other studies have failed to demonstrate consistent counteracting effects of caffeine (Fillmore & Vogel-Sprott, 1995; Liguori & Robinson, 2001). Research reviews also have noted these discrepancies with regard to alcohol-caffeine interactions, leading to conclusions that evidence for caffeine antagonism is equivocal (e.g., Fudin & Nicastro, 1988).

Reasons for these inconsistencies are not clear. However, the tasks used in these studies varied widely in their complexity and in the specific behavioral and cognitive mechanisms involved in their performance (e.g., memory, motor coordination, RT). We recently argued that the equivocal evidence for caffeine antagonism of alcohol-induced impairment might reflect the fact that not all cognitive and behavioral impairments from alcohol can be offset by the coadministration of caffeine. For example, in a study of the

separate and combined effects of moderate doses of alcohol (0.65 g/kg) and caffeine (2.0 and 4.0 mg/kg), we showed caffeine could counteract alcohol-induced slowing of response time but not the disinhibiting effects of the drug (Marczinski & Fillmore, 2003). Thus, it appears that the ability of caffeine to counteract alcohol-induced impairment could depend greatly on the specific nature of the cognitive and behavioral processes involved.

Another important consideration concerns the degree of behavioral demands imposed by the particular activity being performed. It is well known from studies of divided attention that alcohol impairment can be intensified in situations of high behavioral demand (Holloway, 1995; Linnoila, 1974). A divided attention task essentially requires an individual to perform two tasks simultaneously—for example, manually tracking a moving object (e.g., a pursuit task) while performing an auditory discrimination task (e.g., detecting differences among tones). Related are dual-task situations. Typically, dual-task performance is measured by requiring an individual to respond to each of two stimuli (Tasks 1 and 2) presented in very close temporal proximity (for a review, see Pashler, 1994). These situations often illustrate the limits of human information processing. Characteristically, an interference effect is observed as a slowing of response time to the second stimulus (Task 2). The delayed response time to the second stimulus is attributed to the psychological refractory period (PRP) and is assumed to reflect a limitation of information processing in which the response to Task 2 must be delayed until processing of Task 1 is complete (Johnston & Heinz, 1978). Performance in dual-task situations is highly sensitive to the disruptive effects of alcohol. Studies of alcohol effects in dual-task situations show that moderate doses of alcohol dramatically increase task impairment, even in simple tasks that show no impairment from alcohol when performed in isolation (Fillmore & Van Selst, 2002; Schweizer, Jolicoeur, Vogel-Sprott, & Dixon, 2004).

Outside the laboratory, the disruptive effects of alcohol often occur in complex, behaviorally demanding environments that require the simultaneous performance of multiple activities (i.e., the operation of a motor vehicle). Laboratory assessment of dual-task performance may hold greater ecological validity as models of day-to-day performance of activities outside the laboratory. As yet, no research has applied the dual-task PRP model to the investigation of alcohol-caffeine interactions. In the present study, we examined healthy adults and tested the separate and combined effects of alcohol and caffeine on their ability to process information in a dual-task situation. Performance was tested under two active doses and one placebo dose of caffeine (0.0 mg/kg, 2.0 mg/kg, and 4.0 mg/kg) in combination with one active dose and one placebo dose of alcohol (0.0 g/kg and 0.65 g/kg). The active alcohol dose (0.65 g/kg) used in the study has been shown to impair information processing in the dual-task situation (Fillmore & Van Selst, 2002). The active caffeine doses (2.0 mg/kg and 4.0 mg/kg) were selected to approximate the caffeine content found in the various caffeinated beers and mixed alcoholic energy drinks

currently on the market and typically consumed by college students. In addition to examining effects on information processing, the study also examined how this drug combination affects drinkers' subjective reports of intoxication.

## Method

### Participants

Twelve adults (6 women and 6 men) between the ages of 21 and 28 years ( $M = 23.5$ ,  $SD = 2.7$ ) participated in this study. Determination of the appropriate sample size was based on power analyses of data from a previous study that examined alcohol effects on dual-task performance (Fillmore & Van Selst, 2002). The racial makeup of the sample included 1 Asian and 11 Caucasian participants. Participants had a mean weight of 69.6 kg ( $SD = 15.9$ ). Volunteers 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. Volunteers with a score on the Short Michigan Alcoholism Screening Test (Selzer, Vinokur, & Van Rooijen, 1975) of 5 or higher were also excluded from the study.

Recent use of amphetamine, barbiturates, benzodiazepines, cocaine, opiates, and tetrahydrocannabinol was assessed by means of urine analysis. Any volunteer who tested positive for the presence of any of these drugs was excluded from participation. No female volunteers who were pregnant or breast-feeding participated in the research, as determined by self-report and urine human chorionic gonadotropin levels. Participants were recruited via notices posted on community bulletin boards and by local newspaper advertisements. All volunteers provided informed consent prior to participating. The University of Kentucky Medical Institutional Review Board approved the study, and volunteers received \$100 for their participation in the entire seven-session study. Participants completed all of the sessions in 18.8 days on average ( $SD = 4.0$ ).

### Apparatus and Materials

**PRP task.** Participants performed a dual task that required them to respond to two different stimuli (for Tasks 1 and 2) presented in close succession. Task 1 was a go/no-go task. The go stimulus was a *I*, and the no-go stimulus was an *X*. The stimuli were presented in black against a white background. Participants were required to press the *I* key on the keyboard with their right hand when the go stimulus was presented. No response was required when the no-go stimulus was presented. The go/no-go stimuli remained visible for 2,000 ms or were terminated once the response to Task 2 occurred.

Task 2 was an auditory discrimination task. On each trial, the auditory stimulus was either a high tone (1000 Hz) or a low tone (125 Hz). The tone was presented for 500 ms. Using their left hand, participants were required to press the *a* key when the high tone was presented and to press the *z* key when the low tone was presented. Participants had 2,000 ms from the onset of the tone to respond; otherwise, no response was recorded as an error.

Each trial consisted of the following sequence of events: (a) the presentation of a fixation point (an asterisk) for 250 ms; (b) a randomly varying foreperiod of 120, 180, or 240 ms; (c) a Task 1 stimulus (*I* or *X*); and (d) a Task 2 stimulus presented after a stimulus onset asynchrony (SOA) of 50, 200, 600, or 800 ms following the onset of the Task 1 stimulus. Each trial was separated by an intertrial interval of 2,200 ms. To encourage accurate

responding, we displayed a feedback message (the word *INCORRECT*) during the intertrial interval following any incorrect response.

Each test consisted of 192 trials. A test presented an equal number of go and no-go stimuli for Task 1 (i.e., 96) and an equal number of high- and low-tone stimuli for Task 2 (i.e., 96). The four SOAs were presented equally often (48 times). There were 16 possible combinations of these variables for a trial (one possible combination: Task 1 = go stimulus, SOA = 50 ms, Task 2 = low tone). Each combination was presented 12 times during a test in a random order. A test required approximately 10 min to complete. The task was operated using E-Prime experiment generation software (Schneider, Eschman, & Zuccolotto, 2002) and was run on a PC.

**Simple auditory discrimination.** This task was an abbreviated version of the Task 2 component of the PRP task. A test consisted of 40 trials (20 high tone and 20 low tone) in random order. Tone presentation and response requirements were identical to those described in Task 2. A test required approximately 2 min. Unlike the Task 2 component of the PRP task, the simple auditory discrimination task was performed separately as a single task. This task was a control task condition used to evaluate the effect of alcohol and caffeine on simple tone discrimination when no interference from Task 1 was present. The task was also operated using E-Prime.

**Personal Drinking Habits Questionnaire (Vogel-Sprott, 1992).** This questionnaire yielded three measures of a drinker's current, typical drinking habits: (a) frequency (number of drinking occasions per week), (b) dose (milliliters of absolute alcohol per kilogram of body weight typically consumed during a single drinking occasion), and (c) duration (time span, in hours, of a typical drinking occasion).

**Caffeine use questionnaire.** This questionnaire yielded a measure of a participant's typical daily caffeine consumption in milligrams per kilogram of body weight. The questionnaire required participants to report their typical daily consumption of beverages (e.g., coffee, tea, soft drinks) and foods (e.g., chocolate) containing caffeine. Estimates of the caffeine content of foods and beverages were taken from Barone and Roberts (1996).

**Beverage rating scale.** Participants also completed a beverage rating scale to report their perceived intoxication in each dose condition. Participants estimated the alcohol content of the dose they had received in terms of bottles of beer containing 5% alcohol. The scale ranged from 0 to 10 bottles of beer, in 0.5-bottle increments. Previous studies have noted that this beverage rating scale provides a sensitive real-world measure of participants' subjective level of intoxication (Fillmore & Vogel-Sprott, 2000). In previous studies, individuals gave estimates of the amount of alcohol they thought they had consumed that closely corresponded with the actual dose administered (Marczinski & Fillmore, 2005).

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

### Procedure

Individuals who responded to the advertisements called the laboratory and participated in a telephone-screen interview conducted by a research assistant. Volunteers were told that the purpose of the experiment was to study the effects of alcohol and caffeine on performance. All sessions were conducted in the Human Behavioral Pharmacology Laboratory of the Department of Psychology at the University of Kentucky and began between

10 a.m. and 6 p.m. Before each test session, participants were instructed to fast for 4 hr, abstain from alcohol for 24 hr, and abstain from caffeine for 8 hr. Participants abstained from caffeine for 9.8 hr on average ( $SD = 3.2$ ). Before each session, urine samples were tested for the presence of drug metabolites (On Trak Teststiks; Roche Diagnostics Corporation, Indianapolis, IN) and pregnancy in the female participants (Mainline Confirms HGL; Mainline Technology, Ann Arbor, MI). In addition, a zero BAC was verified for each participant at the start of each session. Participants were tested individually by a research assistant who was unaware of the research hypotheses. All testing was conducted in a small room that consisted of a chair and a desk with a computer that operated the tasks.

**Familiarization session.** During familiarization, participants provided informed consent, were weighed, and completed questionnaires. They also practiced the PRP and simple auditory discrimination tasks.

**Test sessions.** PRP and simple auditory discrimination task performance was tested under a 2 (alcohol dose)  $\times$  3 (caffeine dose) factorial within-subject design that crossed two doses of alcohol (0.0 g/kg and 0.65 g/kg) with three doses of caffeine (0.0 mg/kg, 2.0 mg/kg, and 4.0 mg/kg). Thus, the design examined the extent to which the behaviorally impairing effects of a single active alcohol dose (0.65 g/kg) could be counteracted by two active doses of caffeine (2.0 mg/kg and 4.0 mg/kg). Performance under the resulting six dose conditions was tested on individual sessions that were separated by a minimum period of 24 hr and maximum period of 7 days. Dose administrations were double blind, and dose order across the six sessions was randomized across participants.

**Alcohol and caffeine administration.** Participants were told that they might receive alcohol, caffeine, or both drugs during some or all of the sessions. However, the exact contents of the beverages were never disclosed to participants during the study. Carbonated, lemon-flavored soda was used as the vehicle for alcohol and caffeine administration. Participants consumed the drink within 6 min in all dose conditions. Alcohol and caffeine doses were calculated on the basis of body weight. The 0.65 g/kg alcohol doses were administered as one part absolute alcohol and three parts vehicle. The mean total volume of the drink that the participants consumed was 230 ml. This 0.65 g/kg dose produces an average peak BAC of 80 mg/100 ml approximately 60 min after drinking. The alcohol dose was chosen on the basis of prior research that showed that 0.65 g/kg of alcohol reliably impairs PRP task performance (Fillmore & Van Selst, 2002). The placebo alcohol dose (0.0 g/kg) consisted of the vehicle matched to the total volume of the 0.65 g/kg alcohol dose beverage. A small amount (3 ml) of alcohol was floated on the surface of the vehicle, and the glass was sprayed with an alcohol mist that resembled condensation and provided a strong alcoholic scent as the beverage was consumed. Previous research has shown that individuals report that this beverage contains alcohol (e.g., Fillmore, Carscaden, & Vogel-Sprott, 1998).

The caffeine doses were administered by adding 0.0 mg/kg, 2.0 mg/kg, and 4.0 mg/kg of tasteless, anhydrous caffeine powder to the vehicle, either alone or in combination with the alcohol dose. When mixed in an aqueous solution, this form of caffeine is absorbed rapidly, within 60 min (Bonati et al., 1982). The caffeine doses were chosen because they have been shown to counteract alcohol impairment in other research and also were typical of the caffeine content of the caffeinated, alcoholic beverages currently popular among college students (e.g., Burns & Moskowitz, 1990;

Fillmore, 2003; Fillmore & Vogel-Sprott, 1995; Marcziński & Fillmore, 2003). After dose administration, participants relaxed and read magazines.

**PRP and simple auditory discrimination testing.** Participants' PRP task performance followed by simple auditory discrimination task performance was tested starting 35 min after drinking began, a time corresponding with the ascending period of the blood alcohol curve in the active alcohol dose conditions. Participants completed the PRP task from 35 to 45 min after drinking. From 50 to 55 min, participants completed the simple auditory discrimination task, which was immediately followed by the completion of the beverage rating scale. BACs were measured at 30, 45, 60, and 90 min after drinking in each session, regardless of whether doses contained alcohol. At 90 min postdrinking, the testing portion of the session concluded, and participants relaxed in a waiting room within the laboratory. They received a meal and remained at leisure to read magazines or watch television until their BAC fell below 20 mg/100 ml. Upon completing the final session, participants were paid and debriefed.

### Criterion Measures and Data Analyses

The primary measures in this study concerned the degree to which performance of Task 1 interfered with performance of Task 2. Thus, the primary measure of interest was the PRP interference score, which quantified the level of interference from Task 1 on Task 2 RT. In addition, Task 2 RT (RT2) and errors were analyzed. All of these measures and the associated analyses are described in detail below. In addition, manipulation checks included analyses of Task 1 RT (RT1) and simple auditory discrimination RTs. Dose effects on these basic performance measures were not predicted.

### Task 2 Effects

**RT2.** In a dual-task context, RT2 increases as a function of decreasing SOA. The least interference on RT2 should be evident when Task 2 is presented at the longest period of time (SOA) after Task 1. Therefore, RT2 should be shortest at the longest (i.e., 800-ms) SOA. By contrast, interference on RT2 should be greatest when Task 2 occurs at the shortest period of time after Task 1. Thus, RT2 should be longest at the shortest (i.e., 50-ms) SOA. Dose and gender effects on interference were examined by RT2 scores in each dose condition using a 2 (gender: male or female)  $\times$  2 (alcohol dose: 0.0 or 0.65 g/kg)  $\times$  3 (caffeine dose: 0.0, 2.0, or 4.0 mg/kg)  $\times$  4 (SOA: 50, 200, 600, or 800 ms) mixed-design analysis of variance (ANOVA), where gender was a between-subjects factor and alcohol dose, caffeine dose, and SOA were within-subject factors.

**PRP interference score.** Typically, dual-task interference is quantified by a PRP interference score whereby the magnitude of the interference is calculated as the difference between RT2 at the shortest SOA (maximal interference) and RT2 at the longest SOA (minimal interference). Thus, a PRP interference score can be expressed as a single value:  $RT2_{\text{shortest SOA}} - RT2_{\text{longest SOA}}$  (e.g., Fillmore & Van Selst, 2002; Van Selst, Ruthruff, & Johnston, 1999). Larger PRP scores indicate greater interference. These PRP interference scores were submitted to a 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose) mixed-design ANOVA, where gender was a between-subjects factor and alcohol dose and caffeine dose were within-subject factors. Subsequent post hoc analyses used simple effects *t* tests.

Prior to all analyses, the RT2 data were filtered to eliminate trials with an incorrect response to either Task 1 or Task 2 or an

RT of less than 100 ms or greater than 2,000 ms. The outlier elimination procedures resulted in removal of less than 1% of trials.

*Task 2 errors.* Response errors for Task 2 were submitted to a 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose)  $\times$  4 (SOA) mixed-design ANOVA.

### Task 1 Effects

*RT1.* Dose and gender effects on participants' RT1 to the go targets were analyzed by a 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose) mixed-design ANOVA.

*Task 1 errors.* The number of errors for Task 1 in the present study was less than one per test, and this low level of errors precluded any meaningful analysis.

*Simple auditory discrimination.* Dose and gender effects on participants' simple auditory discrimination RT scores were analyzed by a 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose) mixed-design ANOVA. Overall errors were less than one per test on all simple auditory discrimination tests, regardless of dose and gender, thus precluding statistical analyses.

## Results

### Drinking Habits and Caffeine Use

No gender differences were revealed by *t* tests on any drinking habit measure or caffeine use measure ( $ps > .09$ ). From the Personal Drinking Habits Questionnaire data, the sample reported a mean drinking frequency of 1.6 ( $SD = 0.9$ ) times per week, with a mean dose per occasion of 1.3 ( $SD = 0.5$ ) g/kg. For a person weighing 70 kg, this alcohol dose would approximate five bottles of beer containing 5% alcohol by volume. The mean duration of drinking was 4.3 ( $SD = 1.1$ ) hr. The sample reported a mean daily caffeine use of 6.8 ( $SD = 7.7$ ) mg/kg, which approximates a mean level of daily caffeine exposure of 476 mg. For a person weighing 70 kg, this caffeine dose would approximate two 16-ounce (473 ml "grande" size) cups of Starbucks breakfast blend coffee or about nine 355-ml cans of soft drink, such as Pepsi (McCusker, Goldberger, & Cone, 2003; McCusker et al., 2006).

### BAC

BACs obtained in the three active alcohol dose conditions were examined by a 2 (gender)  $\times$  3 (caffeine dose)  $\times$  4 (time) mixed-design ANOVA. There was no significant main effect involving gender ( $p > .34$ ), caffeine dose ( $p > .40$ ), or any significant interactions ( $ps > .12$ ). Thus, BAC was not affected by gender or by the coadministration of caffeine. A main effect of time,  $F(3, 30) = 15.03, p < .001$ , was obtained, attributable to the rise and decline of BACs during the course of a session. The 0.65-g/kg dose produced a mean BAC of 70.8 mg/100 ml ( $SD = 19.9$ ) at 30 min, just before the test, and rose to 84.1 mg/100 ml ( $SD = 18.2$ ) at 45 min, in the middle of testing. The mean BAC declined to 80.4 mg/100 ml ( $SD = 14.7$ ) at 60 min, at the conclusion of testing, and continued to decline to 64.8 mg/100 ml ( $SD = 12.4$ ) at 90 min after drinking, when the session concluded.

### PRP Task Performance

*PRP interference scores.* PRP interference scores were calculated for each dose condition (PRP interference =  $RT2_{\text{shortest SOA}} - RT2_{\text{longest SOA}}$ ). A 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose) mixed-design ANOVA of the PRP interference scores revealed a significant Alcohol Dose  $\times$  Caffeine Dose interaction,  $F(2, 20) = 4.19, p = .03$ . Figure 1 illustrates this interaction. This figure reveals that PRP interference increased under alcohol alone. This observation was confirmed by a simple effects *t* test that found significantly greater PRP interference under alcohol alone as compared with vehicle,  $t(11) = 3.91, p < .01$ . In addition, the figure shows that the coadministration of both active caffeine doses counteracted the alcohol-induced increase in interference. It was revealed through *t* tests that the coadministration of both active caffeine doses with alcohol significantly reduced the PRP interference as compared with alcohol alone ( $ps < .02$ ). Finally, the figure illustrates that the administration of caffeine alone did not alter PRP interference as compared with vehicle. This observation was confirmed, as PRP interference scores did not differ from the vehicle in either caffeine dose condition ( $ps > .23$ ). There was no significant main effect or interaction involving gender ( $ps > .39$ ).

*RT2.* A 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose)  $\times$  4 (SOA) mixed-design ANOVA revealed a significant Alcohol Dose  $\times$  SOA interaction,  $F(3, 30) = 4.72, p < .01$ . Figure 2 plots the alcohol-alone and vehicle condition to illustrate the interaction. The figure shows the typical dual-task interference (PRP) effect as an increase in RT2 as a function of decreasing SOA. The figure also shows how alcohol affects PRP differently as a function of the SOA. Alcohol had the most pronounced slowing effect at the shortest SOAs, when interference from Task 1 was the greatest. There was no significant main effect or interaction involving gender ( $ps > .36$ ).

*Task 2 errors.* A 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose)  $\times$  4 (SOA) repeated measures ANOVA revealed a main effect of alcohol,  $F(1, 10) = 19.22, p < .01$ . Overall, the mean accuracy was very high but was reduced by alcohol. Participants made an average of 9.1 errors per test when alcohol was administered compared with an average of 5.5 errors per test when alcohol was not administered. Caffeine administration, alone or in combination with alcohol, did not alter error rates ( $ps > .15$ ). In addition, no significant main effect or interaction involving gender was found for Task 2 errors ( $ps > .10$ ).

### Effects on Task 1 and Simple Auditory Discrimination

A 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose) repeated measures ANOVA of participants' RT to the go targets in Task 1 revealed no significant effects ( $ps > .06$ ). Thus, alcohol and caffeine, alone or in combination, had no effect on RT1 performance. The overall mean RT to go targets on Task 1 was 493.3 ( $SD = 135.5$ ) ms.

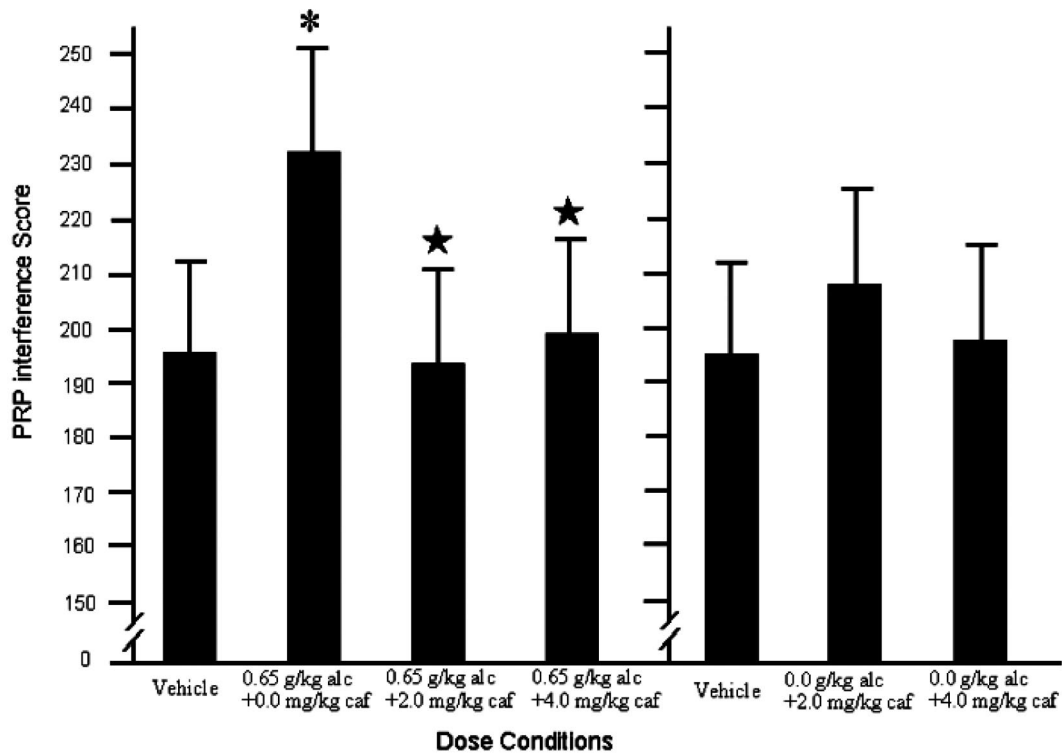


Figure 1. Psychological refractory period (PRP) interference effect scores under the six dose conditions. The graph on the left illustrates alcohol effects in combination with caffeine. The graph on the right illustrates the effects of caffeine administration alone. The vehicle condition, 0.0 g/kg alcohol (alc) + 0.0 mg/kg caffeine (caf), is presented in each graph to facilitate active dose comparison to vehicle. Error bars show standard errors of the mean. \* $p < .05$  for difference from vehicle. \* $p < .05$  for difference from the 0.65 g/kg alc + 0.0 mg/kg caf dose.

A 2 (gender)  $\times$  2 (alcohol dose)  $\times$  3 (caffeine dose) repeated measures ANOVA of participants' RT for simple auditory discrimination revealed no significant effects ( $ps > .09$ ). Thus, alcohol and caffeine, alone or in combination, had no effect on simple auditory discrimination performance. The overall mean RT on the simple discrimination task was 349.2 ( $SD = 62.4$ ) ms.

### Beverage Ratings

Dose and gender effects on the beverage ratings were analyzed by a 2 (gender)  $\times$  2 (alcohol)  $\times$  3 (caffeine) mixed-design ANOVA, which revealed a significant Alcohol  $\times$  Caffeine interaction,  $F(2, 20) = 3.62$ ,  $p < .05$ . Table 1 illustrates this interaction. Participants reported greater perceived alcohol effects under all active alcohol dose conditions, and simple effects  $t$  tests revealed that beverage ratings were greater under alcohol alone as compared with vehicle,  $t(11) = 8.64$ ,  $p < .001$ . Furthermore, coadministration of both caffeine doses reduced the alcohol-induced increase in beverage ratings. Simple effects revealed that coadministration of 2.0 mg/kg of caffeine with alcohol significantly lowered beverage ratings as compared with alcohol alone,  $t(11) = 1.77$ ,  $p = .05$ , but coadministration

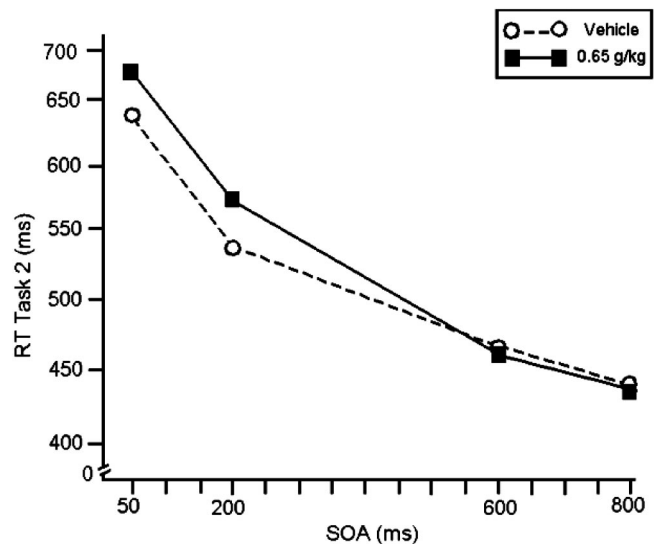


Figure 2. Mean reaction time (RT) to Task 2 following the four stimulus onset asynchronies (SOAs) when 0.65 g/kg alcohol was administered alone compared with vehicle.

Table 1  
*Mean Beverage Rating Scale Scores*

Dose condition	Beverage rating	
	<i>M</i>	<i>SD</i>
Vehicle	1.4	1.2
0.0 g/kg alcohol + 2.0 mg/kg caffeine	2.2	1.4
0.0 g/kg alcohol + 4.0 mg/kg caffeine	1.3	1.2
0.65 g/kg alcohol + 0.0 mg/kg caffeine	5.4	2.3
0.65 g/kg alcohol + 2.0 mg/kg caffeine	4.6	2.4
0.65 g/kg alcohol + 4.0 mg/kg caffeine	4.8	1.7

*Note.* Scores represent participants' estimated amount of alcohol consumed during a session, expressed in terms of standard drinks.

of 4.0 mg/kg of caffeine did not ( $p = .10$ ). Finally, caffeine alone did not significantly alter beverage ratings as compared with vehicle ( $ps > .08$ ). There was no significant main effect or interaction involving gender ( $ps > .18$ ).

### Discussion

This research investigated the separate and combined effects of alcohol and caffeine on constraints on information processing in a dual-task context. The results showed that alcohol impaired information processing in a dual-task context, as measured by the increased PRP to complete a second task performed in close proximity to a first task. Response accuracy to the second task was also impaired by alcohol in the dual-task context. Moreover, alcohol impairment was specific to the dual-task situation, because no alcohol impairment was evident when Task 2 was performed as a single, individual task. The results also showed that the coadministration of caffeine had a nonuniform counteracting effect on the various aspects of performance that were impaired by alcohol. Caffeine doses completely antagonized the alcohol-induced impairment of the PRP interference effect as measured by RT. However, caffeine had no antagonizing effect on the alcohol-induced impairment of accuracy. Thus, the speed of reactions was restored by caffeine, but not the accuracy of these actions. The coadministration of caffeine also attenuated subjective reports of intoxication, as measured by the beverage ratings, as the participants reported feeling less intoxicated when caffeine was coadministered with alcohol as compared with the same dose of alcohol alone. Thus, participants reported reduced intoxication in response to caffeine coadministration despite the fact that aspects of their performance remained impaired (i.e., accuracy).

In this study, we focused on the unique situation of dual-task information processing, as dual-task demands afford a unique and valuable model for understanding the pharmacological effects of alcohol and caffeine, alone and in combination. Although laboratory studies often use single tasks to study the pharmacological effects of various drugs on behavior, single tasks often place only modest demands on participants' cognitive functioning and thus might limit the ability to observe drug-induced impairments. By contrast, dual-task performance affords a more

complex and possibly more naturalistic model of typical human information processing. People's attention is routinely divided among multiple task demands, and the dual-task model captures the complexity of this type of information processing. For example, common tasks performed outside the laboratory, such as driving, are inherently multitask natured and can be further complicated by voluntarily adding other tasks, such as talking on a cellular phone. Moreover, such dual-task activities may be the norm rather than the exception outside the laboratory. The recent application of dual-task models in studies of alcohol effects on behavior shows that performance in dual-task situations is highly sensitive to the disruptive effects of alcohol. Performance in dual-task contexts can be impaired by moderate doses of alcohol that do not impair the individual component tasks (Fillmore & Van Selst, 2002; Schweizer et al., 2004). Accordingly, such single-task analyses may underestimate the magnitude of alcohol impairment associated with moderate doses that might be observed outside the laboratory.

To our knowledge, no prior studies have used dual-task models to examine any drug interactions, such as caffeine-induced antagonism of alcohol impairment. Previous reviews of single-task studies and numerous individual single-task studies have noted mixed findings with regard to caffeine-induced antagonism of alcohol impairment of cognitive and behavioral functions (Gratton-Miscio & Vogel-Sprott, 2005; Hasenfratz, Bunge, Dal Pra, & Battig, 1993; Martin & Garfield, 2006; Nehlig et al., 1992). However, we have recently argued that the equivocal evidence for caffeine antagonism of alcohol-induced impairment might reflect the fact that not all cognitive impairments from alcohol can be offset by the coadministration of caffeine (Marczinski & Fillmore, 2003). In the current study, we also observed a dissociation in caffeine-induced antagonism of alcohol-induced impairment. The moderate doses of caffeine resulted in complete counteraction of alcohol-induced increase in PRP interference, as measured by RT2s. However, these doses of caffeine did not counteract the alcohol-induced impairments on Task 2 response accuracy. Considering that individuals felt less intoxicated when caffeine was coadministered with alcohol, a potentially worrisome outcome may exist when one cognitive function recovers yet another does not. Subjective perceptions of intoxication level may function as feedback for an individual to terminate the drinking episode or to avoid potentially hazardous activities (e.g., driving). However, an individual who perceives less behavioral impairment or feels less intoxicated because of caffeine coadministration with alcohol may decide to continue drinking and/or engage in risky behaviors such as driving.

There are several other factors that might mediate alcohol-caffeine interactions that were not examined in this study. First, the study does not address the role of expectancies, which may be a potentially critical variable in the motivation to consume caffeinated alcoholic drinks. In the current study, dose administration was blind so as to allow determination of the pharmacological effects of these drug

combinations. However, individuals who drink caffeinated alcohol in various forms are fully cognizant of the drug combinations they are consuming. Expectation may play a critical role in the level of impairment observed and contribute to subjective perceptions of intoxication. Indeed, previous studies have noted that individual expectations regarding the counteracting effects of caffeine on alcohol-induced impairment of performance play a large role in the actual performance impairments observed (for a review, see Fillmore, 1999). In illustrating the ironic effects of expectancy, one study led individuals to expect that caffeine would counteract the impairing effects of alcohol. Those individuals displayed much greater impairment on a psychomotor task as compared with individuals who held no such expectation (Fillmore, Roach, & Rice, 2002). One explanation for this finding is that individuals who expect caffeine to counteract some of their behavioral impairment might be less motivated to compensate and resist the impairing effects of alcohol. Given the evidence for the role of drug expectancies as motivators for drug use (Goldman, Del Boca, & Darkes, 1999) and as mediators of the drugged response (Vogel-Sprott & Fillmore, 1999), more information on the role of expectancies in alcohol-caffeine interactions is needed.

The findings of the current study may also be limited to college-age moderate alcohol drinkers who typically consume moderate doses of caffeine on a regular basis. Thus, it is unclear how individuals who do not regularly use caffeine might respond to these drug combinations. With regard to alcohol use, heavier drinkers and binge drinkers might also respond differently to these drug combinations. Time of testing under a dose might also be an important factor. The current study measured behavioral effects during the ascending limb of the blood alcohol curve. Previous work has revealed that various cognitive processes differentially recover over the course of the blood alcohol curve within one drinking episode. For example, subjects who performed a cued go/no-go task demonstrated some recovery in RT, but not in response accuracy, on the descending limb as compared with performance on the ascending limb (Fillmore, Marcziński, & Bowman, 2005). As such, both timing and caffeine coadministration may exacerbate the differential recovery of cognitive processes on the descending limb as compared with the ascending limb of the blood alcohol curve. This scenario has practical implications for potential risky behavior, as individuals are more likely to make decisions about whether to drive on the descending limb, once drinking has concluded.

In summary, the dual-task model appears to be a highly sensitive cognitive measure of the pharmacological effects of moderate doses of alcohol and caffeine, alone and in combination. The results of the current study suggest that the new alcoholic drink preferences for caffeinated alcohol in various forms warrant further investigation. It appears that caffeine coadministration does counteract some aspects of performance that are impaired by alcohol (i.e., response speed) but not others (response accuracy). This finding raises important new questions about the coadministration

of caffeine with alcohol. It is important to determine the extent to which such counteraction of alcohol impairment by caffeine might contribute to alcohol abuse by increasing risk of binge use or other harmful patterns of alcohol consumption. Also, it is unknown what brain mechanisms might be responsible for the lack of uniform counteracting effects of caffeine on impairments of speed and accuracy under alcohol. Functional magnetic resonance imaging analyses of regional brain activity during dual-task performance under these drug combinations could provide some explanation for why caffeine might fail to restore response accuracy. A brain region of particular interest might be the anterior cingulate, which is involved in error monitoring during performance of choice-response tasks similar to our dual-task model (Hester, Fassbender, & Garavan, 2004).

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