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Effects of energy drinks mixed with alcohol on information processing, motor coordination and subjective reports of intoxication

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Abstract

The consumption of alcohol mixed with energy drinks (AmED) has become a popular and controversial practice among young people. Increased rates of impaired driving and injuries have been associated with AmED consumption. The purpose of this study was to examine if the consumption of AmED alters cognitive processing and subjective measures of intoxication compared with the consumption of alcohol alone. Eighteen participants (9 men and 9 women) attended 4 test sessions where they received one of 4 doses in random order (0.65 g/kg alcohol, 3.57 ml/kg energy drink, AmED, or a placebo beverage). Performance on a psychological refractory period (PRP) task was used to measure dual-task information processing and performance on the Purdue pegboard task was used to measure simple and complex motor coordination following dose administration. In addition, various subjective measures of stimulation, sedation, impairment, and level of intoxication were recorded. The results indicated that alcohol slowed dual-task information processing and impaired simple and complex motor coordination. The co-administration of the energy drink with alcohol did not alter the alcohol-induced impairment on these objective measures. For subjective effects, alcohol increases various ratings indicative of feelings of intoxication. More importantly, co-administration of the energy drink with alcohol reduced perceptions of mental fatigue and enhanced feelings of stimulation compared to alcohol alone. In conclusion, AmED may contribute to a high-risk scenario for a drinker. The mix of behavioral impairment with reduced fatigue and enhanced stimulation may lead AmED consumers to erroneously perceive themselves better able to function than is actually the case.

Keywords

alcohol; energy drink; dual-task interference; mental fatigue; stimulation

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Disclosures

All authors declare no real or potential conflicts of interest.

Introduction

Energy drinks are beverages marketed with claims of providing users with increased alertness. These new products contain a variety of compounds including plant-based stimulants (e.g., guarana), simple sugars (e.g., glucose, fructose), amino acids (e.g., taurine), herbs (e.g., ginseng), and very high levels of caffeine (Miller, 2008; O'Brien et al., 2008; Seifert et al., 2011). There has been an exponential rise in sales in the U.S. and worldwide energy drink market (Seifert et al., 2011). While energy drinks are often consumed alone, young people have become enamored with using energy drinks as mixers for alcohol (e.g., Red Bull and vodka or other cocktails like Jagerbombs, which are a mix of Jagermeister and Red Bull). Recently, this practice has become common (Arria et al., 2010; Marczinski, 2011) and has also come under intense scrutiny, especially as research is identifying that consumption of alcohol mixed with energy drinks (AmED) has been associated with greater alcohol-related consequences. Drinking to intoxication, intention to drive while impaired, riding with an intoxicated driver, being physically hurt or injured, requiring medical treatment, and being at risk for alcohol dependence, have all been identified as being greater with AmED consumption, even after adjusting for the amount of alcohol consumed (Arria et al., 2010, 2011; Berger et al., 2011; Miller & Quigley, 2011; O'Brien et al., 2008; Price et al., 2010; Thombs et al., 2010). However, critics argue that the concerns about AmED may be overstated or even unjustified (Siegel, 2011; Skeen & Glenn, 2011; Verster & Alford, 2011). One theme common among such criticisms is that data is derived from self-reports on surveys and that neither causality nor direction of causation can be assumed in nonexperimental studies.

However, the limited experimental studies that do exist examining whether AmED differs from alcohol alone suggest that these beverages may be pharmacologically distinct and may increase the risks associated with alcohol consumption. One laboratory study compared the objective and subjective reactions to the consumption of AmED versus alcohol alone, and found that there are subjective response differences between alcohol and AmED (Ferreira et al., 2006). The authors reported that the acute effects of AmED were associated with reduced perception of headache, dry mouth, and weakness compared to alcohol alone. However, participants were similarly impaired by AmED and alcohol alone on objective measures of simple reaction times and simple motor coordination. A second laboratory study compared objective and subjective reactions to the consumption of AmED versus alcohol alone, using a variety of different measures (Marczinski et al., 2011). The acute effects of AmED were associated with enhanced perceptions of stimulation compared to alcohol alone. Moreover, performance on a cued go/no-go task indicated that participants were less impaired by AmED for reaction times to go targets, compared to alcohol alone. However, behavioral inhibition deficits were similar for AmED and alcohol for the same task. The findings from this study might suggest that the mix of impaired behavioral inhibition and enhanced feelings of stimulation is the combination that may make AmED consumption riskier than alcohol consumption alone. However, this literature remains unclear given that the above two studies used similar doses of the energy drink, Red Bull, with alcohol and one study found that the energy drink antagonized alcohol's impairing effects on reaction times (Marczinski et al., 2011), whereas another did not (Ferreira et al., 2006). Interestingly, one animal study also revealed that an energy drink could antagonize some of the alcohol-induced impairment of locomotor activity in mice (Ferreira et al., 2004).

The above described inconsistencies in the recent literature of whether an energy drink can antagonize alcohol-induced impairment of behavior also have been observed in the larger literature on the acute effects of caffeine and alcohol in combination. Laboratory research has indicated that the co-administration of caffeine with alcohol often reduces participants' subjective perceptions of alcohol intoxication compared with the administration of alcohol

alone. However, the evidence that the co-administration of caffeine can counteract the impairing effects of alcohol on a variety of behavioral and cognitive tasks is equivocal (for a review, see Fudin & Nicastro, 1988). Some studies have shown that caffeine coadministration can reduce the impairing effects of alcohol on 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, Bickel, & Wiegner, 1993). By contrast, other studies have failed to demonstrate consistent counteracting effects of caffeine (Fillmore & Vogel-Sprott, 1995; Howland et al., 2010; Liguori & Robinson, 2001). While the reasons for these inconsistencies still remain unclear, we have argued that the ability of caffeine to counteract alcohol-induced impairment could depend on the specific nature of the cognitive and behavioral processes involved (Marczinski & Fillmore, 2006).

To our knowledge, comparisons of the acute effects of AmED versus alcohol alone on dual-task information processing and simple and complex motor coordination have not been made. Alcohol impairment is known to be intensified in situations of high behavioral demand, such as divided attention tasks or dual-task environments (Holloway, 1995). Outside the laboratory, the disruptive effects of alcohol often occur in behaviorally demanding and complex environments that require the simultaneous performance of multiple activities. Thus, laboratory assessment of dual-task performance may hold greater ecological validity as models of day-to-day performance of activities outside the laboratory. Prior research has found that alcohol-induced impairment of dual task information processing was shown to be antagonized with caffeine (Marczinski & Fillmore, 2006). However, the combined effects of energy drinks and alcohol may differ from the combined effects of caffeine and alcohol, given that energy drinks contain a variety of compounds, and not just caffeine (Seifert et al., 2011). Thus, a comparison of AmED versus alcohol on various cognitive and motor processes, as well as measuring subjective reactions to these beverages, is warranted.

Therefore, the purpose of this study was to examine the acute effects of alcohol and energy drinks, alone and in combination, on objective and subjective measures. Information processing in a dual-task context and simple and complex motor coordination were measured. In addition, a variety of subjective measures of intoxication were assessed. Participants attended four test sessions where they received one of four possible doses (alcohol, energy drink, AmED, or placebo). Following dose administration, performance on a PRP task was used to measure information processing in a dual-task context and motor coordination was assessed using the Purdue pegboard task. Based on prior research examining the combined effects of energy drinks and alcohol (Marczinski et al., 2011), it was predicted that the co-administration of an energy drink with alcohol would reduce perceptions of fatigue and increase stimulation compared to alcohol alone. In addition, these subjective changes that differ between AmED and alcohol alone should occur independently of whether or not the co-administration of an energy drink with alcohol alters alcohol-induced impairment of dual-task information processing and simple and complex motor coordination.

Materials and Methods

Participants

Eighteen adults (9 men and 9 women) between the ages of 21 and 28 years ($M = 22.89$, $SD = 2.47$) participated in this study. The racial makeup of the sample included 3 African-American and 15 Caucasian participants. Participants had a mean weight of 75.5 kg ($SD = 4.07$). Volunteers completed questionnaires that provided demographic information, alcohol and caffeine use habits, and physical and mental health status. Exclusion criteria included a

self-reported psychiatric disorder, substance use disorder, head trauma, or other CNS injury. In addition, volunteers with a score of the 5 or higher on the Short Michigan Alcoholism Screening Test (Selzer et al., 1975) and/or a score of 8 or higher on the Alcohol Use Disorders Identification Test (Babor et al., 1989) were also excluded from study participation because of the risk for dependence (Barry & Fleming, 1993; Schmidt et al., 1995). Furthermore, individuals who did not regularly consume alcohol (i.e., fewer than 2 standard drinks per month) were excluded because of ethical concerns of administering a 0.65 g/kg dose of alcohol to an individual unfamiliar with that dose of alcohol. Inclusion criteria included the self-reported consumption of 1 energy drink in the past year, and having consumed at least 1 caffeinated beverage in the past 2 weeks (e.g., soft drink, tea, coffee, chocolate, and/or energy drink). All participants had normal or corrected-to-normal visual acuity and normal color vision. Two of our participants were left-handed and two of our participants were smokers.

Recent use of benzodiazepines, barbiturates, tetrahydrocannabinol, cocaine, amphetamines, and opiates was assessed by means of urinalysis at the start of each session. Participants were informed that any volunteer who tested positive for the presence of any of these drugs would be excluded from the study. No participants needed to be discontinued for this reason. No female volunteers who were pregnant or breast-feeding participated in the research, as determined by self-report and urine gonadotrophin (HCG) levels assessed at the start of each session. Participants were recruited through notices posted on community bulletin boards at the university. All volunteers provided informed consent before participating. The Northern Kentucky University Institutional Review Board approved this study, and volunteers received \$130 for their participation in the entire 5 session study.

Apparatus and Materials

Personal Drinking Habits Questionnaire (PDHQ: Vogel-Sprott, 1992)—The PDHQ measures an individual's current, typical drinking habits including: (a) number of standard drinks (i.e., bottles of beer, glasses of wine, and shots of liquor) typically consumed during a single drinking occasion, (b) weekly frequency of drinking, and (c) hourly duration of a typical drinking occasion. The PDHQ also measures previous experience with alcohol in terms of the number of months that an individual has been drinking on a regular basis or customarily on social occasions.

Caffeine Use Questionnaire (CUQ)—This questionnaire provides a measure of a participant's daily caffeine consumption in milligrams per kilogram of body weight. Estimates of the caffeine content in foods and beverages were taken from Barone and Roberts (1996), McCusker et al. (2006), and manufacturer websites for newer products.

PRP Task—Participants performed a dual task to measure information processing rates on a laptop computer. That task required the response to 2 different stimuli (for Tasks 1 and 2) presented in close succession. Task 1 was a go/no-go task. The go stimulus was a 1, and the no-go stimulus was an X. The stimuli were presented in black against a white background on the computer screen. Participants were instructed to press the 1 key on the keyboard with their left 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 2000 ms or were terminated once the response to Task 2 occurred.

Task 2 was an auditory discrimination task. On each trial, participants heard an auditory stimulus that was either a high tone (1000 Hz) or a low tone (125 Hz). The tone was presented for 500 ms. Participants were instructed 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 2000 ms

from the onset of the tone to respond. If no response was made, this was recorded as an error.

Each trial consisted of the following sequence of events: (1) the presentation of a fixation point (*) for 250 ms, (2) a randomly varying foreperiod of 120, 180, or 240 ms, (3) a Task 1 visual stimulus (1 or X), and (4) a Task 2 auditory stimulus (high or low tone) 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. Participants were instructed to try to be fast as well as accurate. To encourage accurate responding, a feedback message (the word INCORRECT) was presented during the intertrial interval following any incorrect response.

Each test consisted of 192 trials. A test presented an equal number of go (1) and no-go (X) stimuli for Task 1 (i.e., 96) and an equal number of high and low tone stimuli for Task 2 (i.e., 96). The 4 SOAs were presented equally often (48 times). There were 16 possible combinations of these 3 variables for each trial and each combination was presented 12 times during a test in a random order. A test required approximately 10 minutes to complete. That task was operated using E-Prime 2.0 experiment generation software (Schneider et al., 2002) and was run on a Dell Latitude laptop computer.

Simple Auditory Discrimination—An abbreviated version of the Task 2 component of the above described PRP task was used to test simple auditory discrimination. A total of 40 trials (20 high tones and 20 low tones) were presented in random order. Tone presentation and response requirements were identical to that described for Task 2 of the PRP task. A test required approximately 2 min. to complete. This task was the control task condition used to evaluate the effects of alcohol and energy drinks on simple tone discrimination when no interference from Task 1 was present.

Purdue Pegboard Dexterity Task—Motor coordination was measured using a grooved pegboard task assessing two types of motor dexterity: gross movements of the fingers, hands, and arms, and fine finger dexterity necessary in assembly tasks (Lafayette Instruments, Lafayette, IN). Participants were placed in front of a pegboard and were instructed to pick up pins one at a time and fill the 25 grooves on the board one row at a time from left to right. Subjects perform 4 trials with different response requirements. For the first 3 trials, participants use: 1) their right hand to pick up and place pins, 2) their left hand to pick up and place pins, and 3) both hands simultaneously to pick up and place pins. For the fourth trial, participants were instructed to pick up and place in the groove as many pins as possible within 30 seconds. On the fourth trial, participants are instructed to use both hands in a continuous motion to create as many assemblies (i.e., pin, collar, washer, and collar) as possible within one minute.

Biphasic Alcohol Effects Scale (BAES; Martin et al., 1993)—Subjective ratings of stimulation and sedation were evaluated using this 14-adjective rating scale where 7 adjectives describe stimulation effects (e.g., stimulated, elated) while the remaining 7 describe sedation effects (e.g., sedated, sluggish). Participants rated each item on an 11-point Likert-type scale ranging from 0 (not at all) to 10 (extremely) and Stimulation and Sedation scores were summed separately (score subscale range = 0-70).

Subjective Effect Ratings—A 5-item 100 mm visual analogue scale was used to assess the subjective effects of the dose administered with end anchors of *not at all* and *very much*. Two items asked participants to rate the subjective effects of the drink in terms of how much they “feel the drink” (feel) and “like the effects” (like) (Fillmore, 2001). The other three

items asked subjects to rate their overall level of impairment, mental fatigue, and ability to drive at the time of the rating (Beirness, 1987).

Intoxication and Willingness to Pay Ratings—The intoxication rating scale (Fillmore & Vogel-Sprott, 2000) asks subjects to report their perceived level of intoxication by reporting the perceived alcoholic content of the beverage administered in terms of bottles of beer containing 5% alcohol. The scale ranges from 0 to 10 bottles of beer, in 0.5 bottle increments. In addition, participants were asked to rate what they would be willing to pay for the beverage they had received. The scale ranges from \$0.00 to \$10.00, in \$0.50 increments.

Procedure

Pre-laboratory Screening—Individuals who responded to the advertisements contacted the research assistant by e-mail to set up a time to participate in a telephone intake-screening interview conducted by the research assistant. During the telephone interview, volunteers were informed that the purpose of the experiment was to study the effects of alcohol and energy drinks on behavioral and mental functioning. Volunteers were told that they would be asked to come to the lab for five sessions to perform computerized tasks and complete questionnaires. Moreover, they were informed that they would receive a beverage to consume on all sessions except the first one, and that the beverage they would receive on each session could contain the maximum dose of alcohol found in 4 beers and the maximum dose of caffeine found in a cup of coffee or 2 cans of a soft drink. The research assistant determined if the participant met all eligibility requirements to participate. Eligible subjects then made an appointment for the first treatment session.

All sessions were conducted in the Psychology department laboratory at Northern Kentucky University and began between 10 a.m. and 6 p.m. Participant start times differed for each participant and the mean (*SD*) maximum start time difference for all sessions was 3.1 (2.8) hr. For example, an average participant might have the earliest start time of 1 p.m. and the latest start time of 4 p.m. Prior to each session, participants were required to fast for 2 hours, abstain from any form of caffeine for 8 hours and abstain from alcohol for 24 hours. Smokers ($n = 2$) were asked to not smoke during the sessions. At the start of each test session, subjects were then asked to provide a urine sample in a private bathroom. Urine samples were tested for the presence of drug metabolites for all participants and HCG for women only (Bioscreens Inc., Norfolk, VA). After urine drug/pregnancy testing, a zero blood alcohol concentration (BAC) was verified from participants, as determined from breath samples measured by an Intoxilyzer, Model 400 (CMI Inc., Owensboro, KY). All testing was conducted in a small room that consisted of a chair and a desk with the computer that operated the PRP task. Participants were tested individually by a research assistant.

Familiarization session—When participants arrived at the laboratory, they were asked to provide informed consent. Then, participants were weighed and completed alcohol use and caffeine use questionnaires. Participants also practiced the PRP, simple auditory discrimination and pegboard tasks.

Test sessions—Behavioral and subjective responses were tested under 4 dose conditions (placebo, 0.65 g/kg alcohol, 3.57 ml/kg energy drink, and 0.65 g/kg alcohol + 3.57 ml/kg energy drink). Performance under the 4 dose conditions was tested on individual sessions that were separated by a minimum period of 24 hr and a maximum period of 7 days. Dose administrations were double blind, and dose order across the 4 sessions was randomized across participants.

Dose administration—Participants were informed that they might receive alcohol, energy drink, decaffeinated soft drink or a combination of these during all of the test sessions. However, the exact contents of the beverages were never disclosed to the participants during the course of the study. Doses were calculated on the basis of body weight. For the alcohol dose, male participants received a 0.65 g/kg dose of alcohol (using 40% alcohol/volume Smirnoff Red Label vodka, No. 21, Smirnoff Co., Norwalk, CT), a dose that produces an average peak blood alcohol concentration (BAC) of .08 g% which is the legal limit for driving. Female participants received a 0.57 g/kg dose of alcohol, and this reduced dose was administered as women tend to achieve higher BACs than do men. For men and women, the alcohol dose approximated 4 and 3 standard drinks, respectively. The alcohol dose was mixed with a 3.57 ml/kg of Squirt, a decaffeinated soft drink (Dr. Pepper Snapple Group, Plano, TX) resulting in a 2:1 (soft drink:alcohol) ratio.

For the alcohol+energy drink condition, the 0.65 g/kg dose of alcohol was mixed with 3.57 ml/kg of Red Bull energy drink (Red Bull, Switzerland). This alcohol+energy drink mix was chosen because this 2:1 ratio (Red Bull:vodka) is the mixed drink typically served in bars. In the energy drink condition, subjects received 3.57 ml/kg Red Bull, and in the placebo condition, subjects received 3.57 ml/kg Squirt. In both the energy drink and placebo conditions, 10 ml of vodka was floated on the surface of the beverage to give the drink an alcohol scent. Previous research has demonstrated that individuals report that this beverage contains alcohol (Marczinski et al., 2011; Marczinski & Fillmore, 2006). Red Bull was chosen as the energy drink beverage because it is the most commonly purchased energy drink in the U.S. market and the most commonly used energy drink mixed with alcohol (Bryce & Dyer, 2007). A carbonated, lemon-flavored decaffeinated soda (Squirt) was chosen as the placebo beverage as it was found to be most similar in taste, carbonation and appearance to the energy drink. The 3.57 ml/kg energy drink dose resulted in the consumption of 91 mg of caffeine for the typical 76 kg participant. The energy drink and placebo beverages were approximately equivalent in calories and glucose content.

Participants were given their beverage in a plastic cup and were asked to consume the drink within 10 minutes. Drinking was self-paced. After dose administration, participants relaxed and read magazines. BACs were measured at 30, 40, 70, 80, 90 and 120 min. after drinking. During the energy drink and placebo sessions, participants also provided breath samples at those times ostensibly to measure their BAC.

Testing battery—At 45 minutes after drinking began, participants' performance on the auditory discrimination and PRP task was tested. Thus, the test occurred during the ascending to peak period when both alcohol and caffeine are most active. After the PRP test (60 minutes after drinking began), participants completed the BAES and ratings of subjective effects, subjective intoxication, and willingness to pay for the drink administered. These measures were typically completed within 5 minutes. At 65 minutes after drinking began, participants' performance on the pegboard task was tested.

Detoxification period—Upon completion of the testing period, participants relaxed in a waiting room in the laboratory. Participants received a hot meal and snacks and remained at leisure to read magazines or watch DVDs until their BAC fell below .02 g%, at which time they were released. Participants who had not received alcohol were immediately released after the testing battery concluded. All participants were paid and debriefed following the completion of the final session.

Criterion Measures and Data Analyses

PRP task performance—To measure dual-task information processing capacity, the psychological refractory period (PRP) task measures the degree to which performance on Task 1 interferes with performance on Task 2. Typically, dual-task interference is quantified by a PRP interference score whereby the magnitude of the interference is calculated as the difference between RT₂ and the shortest SOA (i.e., maximal interference from Task 1) and RT₂ at the longest SOA (i.e., minimal interference from Task 1), collapsed across Task 1 target type (1 vs. X). Thus, a PRP interference score can be expressed as a single value: $RT_{2\text{shortest SOA}} - RT_{2\text{longest SOA}}$ (e.g., Fillmore & Van Selst, 2002). Larger PRP scores indicate greater interference. Previous research indicates that the acute effects of alcohol increase PRP scores, indicating greater interference (Fillmore & Van Selst, 2002; Marczinski & Fillmore, 2006).

The PRP interference scores were submitted to a 2 (Sex: male vs. female) $\times$ 2 (Alcohol Dose: 0.65 g/kg vs. 0.0 g/kg) $\times$ 2 (Energy Drink Dose: 3.57 ml/kg vs. 0.00 ml/kg) mixed design ANOVA, where Sex was treated as a between subjects variable and Alcohol Dose and Energy Drink Dose were treated as within subjects variables. Prior to all analyses, the RT data were filtered to eliminate trials with an incorrect response to either Task 1 or Task 2 or RT of less than 100 ms or greater than 2,000 ms. Removal of these outliers resulted in removal of less than 1% of trials. In addition to the PRP interference score for RT, the same PRP interference score was analyzed for accuracy data. In addition, manipulation checks included analyses of RT and accuracy for simple auditory discrimination task performance. Dose effects on these basic performance measures were not predicted (see Fillmore & Van Selst, 2002; Marczinski & Fillmore, 2006).

Motor coordination and subjective effects—Dose effects on participants' motor coordination were measured as the number of correctly placed pegs within the time limit. Prior research indicated that the acute effects of alcohol decrease the number of correctly placed pegs (Breckenridge & Berger, 1990; Ostling & Fillmore, 2011). The number of correctly placed pegs for each trial were analyzed by separate 2 (Sex) $\times$ 2 (Alcohol Dose) $\times$ 2 (Energy Drink Dose) mixed design ANOVAs. Similarly, participants' subjective ratings were analyzed by separate 2 (Sex) $\times$ 2 (Alcohol Dose) $\times$ 2 (Energy Drink Dose) mixed design ANOVAs.

The alpha level was set at .05 for all statistical tests and a Bonferroni correction was applied to the planned comparisons when multiple statistical tests were required. SPSS 17.0 was used to conduct all analyses.

Results

Demographic Characteristics and Self-reported Caffeine and Alcohol Use

No sex differences were revealed by *t* tests on any drinking habit measure or caffeine use measure (*ps* > .18). From the Personal Drinking Habits Questionnaire data, the sample reported a mean (*SD*) weekly alcohol drinking frequency of 1.8 (0.94), with a mean (*SD*) number of standard drinks per occasion of 4.3 (3.07). The mean (*SD*) duration of drinking was 2.7 (1.64) hr. The sample reported a mean (*SD*) daily caffeine use of 2.5 (2.02) mg/kg, which approximates a mean level of daily caffeine exposure of 188 mg. For a person weighing 75 kg, this caffeine dose would approximately 4 355-ml cans of soft drink, such as Pepsi (McCusker et al., 2006) or slightly more than 2 255-ml cans of a Red Bull energy drink.

BACs

No detectable BACs were observed under the placebo or energy drink conditions. BACs obtained in the 2 active alcohol dose conditions were examined by a mixed-design ANOVA. There was no significant main effect involving sex ($p > .18$), energy drink dose ($p > .90$), or any significant interactions ($ps > .31$). Thus, BAC was not affected by sex or by the coadministration of the energy drink. A main effect of time, $F(5,12) = 51.09$, $p < .001$, was obtained, attributable to the rise and decline of BACs during the course of the session (see Table 1).

PRP Task Performance

PRP interference scores for mean reaction times were calculated for each dose condition, (PRP interference = $RT_{2\text{shortest SOA}} - RT_{2\text{longest SOA}}$). An ANOVA of the PRP interference scores revealed a significant main effect of alcohol, $F(1,16) = 5.18$, $p = .037$. Figure 1 illustrates that PRP interference was greater under the alcohol dose conditions compared to the conditions when alcohol was not administered. There were no other main effects or interactions for this analysis, $ps > .43$.

PRP interference scores for mean accuracy were calculated for each dose condition (PRP interference = $ACC_{2\text{shortest SOA}} - ACC_{2\text{longest SOA}}$). An ANOVA of the PRP interferences scores for accuracy revealed no main effects or interactions, $ps > .22$.

Simple Auditory Discrimination

An ANOVA of participants' mean RT for simple auditory discrimination revealed no significant main effects or interactions, $ps > .10$. Thus, alcohol and energy drink, alone or in combination, had no effect on simple auditory discrimination.

Pegboard Task Performance

Table 1 illustrates the mean number of pegs placed for the 4 trials of the pegboard task: 1) right hand, 2) left hand, 3) both hands, and 4) assembly. Task performance for the 4 trials was analyzed by separate ANOVAs. For the left hand trial, a main effect of alcohol, $F(1,16) = 15.03$, $p = .001$, was obtained. Table 1 illustrates that the mean number of pegs placed was reduced for the alcohol conditions compared to when alcohol was not administered. There were no other significant main effects or interactions for this analysis, $ps > .19$. For the both hands trial, a main effect of alcohol, $F(1,16) = 5.10$, $p = .038$, was obtained. Table 1 illustrates that the mean number of pegs placed using both hands was reduced for the alcohol conditions compared to when alcohol was not administered. There were no other significant main effects or interactions for this analysis, $ps > .41$. For the assembly condition, a main effect of alcohol, $F(1,16) = 11.46$, $p = .004$, was obtained. Table 1 illustrates that the mean number of assembled items was reduced for the alcohol conditions compared to when alcohol was not administered. There were no other significant main effects or interactions for this analysis, $ps > .11$. Finally, for the right hand trials, there were no significant main effects or interactions for this analysis, $ps > .08$.

Subjective Ratings

Table 1 illustrates the mean stimulation, sedation, mental fatigue, subjective intoxication, feel the drink, like the drink, impairment, ability to drive and willingness to pay ratings that were administered 60 minutes after the onset of dose administration. Subjective ratings were analyzed by separate ANOVAs. For the willingness to pay ratings, a main effect of alcohol, $F(1,16) = 40.69$, $p < .001$, and a main effect of energy drink, $F(1,16) = 16.34$, $p = .001$, was obtained. Table 1 reveals that participants were willing to pay more for an alcohol beverage compared to a beverage that did not contain alcohol and participants were willing to pay

more for an energy drink beverage compared to a beverage that did not contain an energy drink. There was no main effect of sex and no significant interactions for this analysis ($p > .12$).

For feel the drink ratings, a significant interaction of alcohol and energy drink, $F(1,16) = 9.32$, $p = .008$, was obtained. There was no main effect of sex and no other significant interactions for this analysis ($p > .17$). Simple effects comparisons confirmed that feel ratings were significantly higher following all 3 active dose conditions compared with placebo, $ps < .03$. Feel ratings were not significantly different for the alcohol and AmED conditions, $p > .26$.

For the mental fatigue ratings, there was a main effect of alcohol, $F(1,16) = 16.86$, $p = .001$, and a nonsignificant trend for an alcohol $\times$ energy drink interaction, $F(1,16) = 2.96$, $p = .10$. There was no main effect of sex and no other interactions for this analysis ($ps > .15$). Figure 2 illustrates that mental fatigue ratings were highest in the alcohol condition compared to the other dose conditions. Simple effect comparisons confirmed that fatigue ratings were significantly higher in the alcohol condition than the placebo condition, $t(17) = 4.44$, $p < .001$. Moreover, the fatigue ratings were significantly higher in the alcohol condition compared to the AmED condition, $t(17) = 2.74$, $p = .014$. There were no other significant comparisons, $ps > .05$.

For stimulation ratings, there was a non-significant trend for an alcohol energy drink interaction, $F(1,16) = 2.41$, $p = .14$. There was no main effect of sex and no other significant interactions ($ps > .37$). Figure 3 illustrates that stimulation ratings were highest for the AmED dose condition compared to the other conditions. Simple effect comparisons confirmed that stimulation ratings were significantly higher in the AmED condition compared with the alcohol condition, $t(17) = 2.17$, $p = .045$, and there was a nonsignificant trend that stimulation ratings in the AmED condition were higher than the placebo condition, $t(17) = 1.98$, $p = .064$. There were no other significant comparisons, $ps > .38$.

Finally, for analyses of ratings of sedation, impairment, ability to drive and subjective intoxication, all analyses revealed main effects of alcohol, $ps < .001$ (see Table 1). Participants rated greater sedation, greater impairment, greater subjective intoxication, and reduced ability to drive under alcohol conditions compared to conditions where alcohol was not administered (see Table 1). No other significant main effects or interactions were obtained for these analyses, $ps > .17$. The analysis for like ratings revealed no significant main effects or interaction, $ps > .22$.

Discussion

This research examined the separate and combined effects of alcohol and energy drinks on dual-task information processing, simple and complex motor coordination, and subjective reports of intoxication. The results showed that alcohol impaired dual-task information processing, as measured by the increased PRP interference scores, which records how much extra time is needed to complete a second task performed in close proximity to a first task. This alcohol impairment was specific to the dual-task situation, given that alcohol impairment was not observed when Task 2 was performed as a single, individual task (i.e., simple auditory discrimination). The results also showed that the energy drink, alone and in combination with alcohol, had no effects of dual-task information processing. Similar findings were observed with simple and complex motor coordination. Alcohol impaired both simple and complex motor coordination, as measured by the peg placement trials and the assembly trials, respectively. The results also showed that the energy drink, alone and in combination with alcohol, had no effects of simple and complex motor coordination

performance. Finally, the subjective ratings revealed that participants' reported feeling less mental fatigue and greater stimulation following administration of AmED compared to alcohol alone, indicating that co-administration of the energy drink with alcohol altered subjective state differently than the same dose of alcohol alone.

The results of this study are consistent with prior research that has found that the benefits of co-administration of an energy drink may be limited to subjective changes, versus objective benefits of alcohol-induced behavioral impairment (Ferreira et al., 2006). Reports of greater subjective stimulation and reduced mental fatigue from our participants, are consistent with self-reported motivations reported by AmED consumers for why they choose these beverages over other types of alcoholic beverages (Marczinski, 2011). However, it is interesting that prior work has demonstrated that both 2.0 and 4.0 mg/kg doses of caffeine have antagonized alcohol-induced impairment of PRP interference (Marczinski & Fillmore, 2006). In the current study, the caffeine in the Red Bull dose was approximately 1.2 mg/kg. Therefore, the difference between the current results using the energy drink Red Bull and the prior report using anhydrous caffeine powder mixed with alcohol possibly reflects the fact that 2.0 mg/kg of caffeine might be a threshold dose for observing a counteracting effect on alcohol-inducement impairment of dual-task information processing. This explanation seems possible given that differences between the past and current study cannot be attributed to the typical caffeine use and alcohol use habits of the participants, as they were similar in two studies. While we choose the 3.57 ml/kg Red Bull dose to reflect current real-world consumption practices where 2 parts Red Bull is typically mixed with 1 part vodka, it should be noted that this version of this mixed AmED is not universal. Various bars serve and mixology websites recommend 3 parts Red Bull with 1 part vodka and/or Jagerbombs, served depth-charge style, which involves dropping a 1 ½ ounce shot glass of Jagermeister into a typical beer glass containing a full 255 ml can of Red Bull. Such practices increase the proportion of Red Bull consumed with the alcohol. Consequently, studies of the effects of increased doses of Red Bull with alcohol should be studied under controlled laboratory conditions.

In this study, we tested participants around the peak section of the blood alcohol curve and the dose was moderate, given that peak BACs reached approximately .07 g%, for both the alcohol and AmED conditions. Future research is needed to determine the effects of AmED versus alcohol for higher doses of alcohol and for all portions of the blood alcohol curve. Examining higher doses is important given that AmED beverages have been associated with binge drinking and alcohol dependence (Arria et al., 2010, 2011; Price et al., 2010; Thombs et al., 2010). In addition, individuals who receive a moderate dose of alcohol typically report stimulation on the rising limb and sedation on the declining limb (Martin et al., 1993). It is possible that co-administration of energy drinks with alcohol could ameliorate sedative effects on the declining limb, thus encouraging an individual to drink more alcohol and for longer periods of time. This could be a problem, especially since the majority of decisions to drive are made on the descending limb of the blood alcohol curve (Jones, 1990; Levine & Smialek, 2000; Shore et al., 1998). A recent field study reported that AmED users were more likely to consider driving home compared to alcohol users (Thombs et al., 2010), although the portion of the blood alcohol curve where this judgment was made was not known. In the current study, ratings regarding driving ability were given while BAC was peaking and these ratings were equivalent in the alcohol and AmED dose conditions. In future, it would be important to ask this same question about willingness to drive on the declining limb. To further complicate matters, previous work has established that binge drinkers exhibit higher willingness to drive ratings following alcohol consumption compared to their more moderate drinking peers, especially on the descending limb of the blood alcohol curve (Marczinski & Fillmore, 2009). Given that AmED consumers are at increased likelihood of being alcohol dependent (Arria et al., 2011), it remains to be determined

whether the Thombs et al. (2010) field study results were derived because of the pharmacological effects of the AmED drink, or because of the characteristics of the AmED consumer.

This study raises some questions, some of which are due to limitations of the current study design. We examined one type of energy drink brand (Red Bull) and one dose of alcohol in this study. Given the repeated testing required of this design, we weighed the benefit of a within-subjects design with the limitation of examining other energy drink brands and different doses of alcohol and energy drinks. However, future studies should examine the variety of different energy drinks to determine the importance of the various constituent ingredients, including caffeine, taurine, glucose and other ingredients. While energy drinks contain significant amounts of caffeine, it is unknown whether or not the additional compounds may have contributed to the results of the present study. In addition, doses of alcohol above and below the level used in the current study (0.65 g/kg alcohol) are needed, especially as inferences about potential pharmacological mechanisms of AmED would require dose-response curves. Finally, it is important to recognize that the relatively small sample size in this study precluded any analyses regarding individual difference variables that may be of great importance. Future studies are needed to examine other factors (e.g., sex, sensation-seeking status, impulsivity, binge drinking status, typical caffeine use habits) that may exacerbate or ameliorate differences between the effects of AmED and alcohol. It would also be advantageous to examine whether differences in session start times impact differences between the effects of AmED and alcohol, given that there was some variability in when participants started sessions in this study.

In conclusion, the results of the present study suggest that differences between AmED and alcohol may be limited to subjective changes in the individual, such as feelings of stimulation and mental fatigue. Results from the objective measures of dual-task information processing and motor coordination indicated that impairment was similar between the alcohol and AmED dose conditions. Given that AmED beverages have been implicated in impaired driving and AmED consumption is considered a risky drinking practice, a closer examination of the effects of these drinks is warranted. Future research should compare the effects of AmED and alcohol for simulated driving performance and subjective ratings of driving ability. The findings of this study suggest that if impaired driving is more likely following AmED consumption, it appears likely that individuals are judging themselves to be less impaired by alcohol, and not that their objective alcohol-induced behavioral impairment, at least as it pertains to their driving skills, is reduced.

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Figure 1. Psychological refractory period (PRP) interference effect scores under the four dose conditions. Error bars show standard errors of the mean.

Figure 2.
Mean ratings of mental fatigue under the four dose conditions. Error bars show standard errors of the mean.

Figure 3. Mean ratings of stimulation under the four dose conditions. Error bars show standard errors of the mean.

Table 1

Pegboard task performance and subjective ratings for the 4 dose conditions and blood alcohol concentrations for the 2 alcohol dose conditions. Participants gave the subjective ratings at 60 min. and performed the pegboard trials at 70 min. after the onset of dose administration.

Variable	Dose Condition						ANOVA Results ^a			
	Placebo		Energy Drink		Alcohol		AnED		A	
	M	SD	M	SD	M	SD	M	SD	p	p
<i>BACs (g%) at</i>										
30 min					.062	.016	.063	.016		
40 min					.071	.013	.069	.014		
70 min					.063	.012	.065	.011		
80 min					.061	.014	.061	.010		
90 min					.057	.013	.058	.008		
120 min					.049	.012	.048	.009		
<i>Pegboard trials</i>										
Right hand	16.17	1.43	15.83	2.04	15.39	1.98	15.61	1.61	.14	.85
Left hand	15.39	1.38	15.39	1.50	14.33	1.24	14.50	1.43	.001	.76
Both hands	12.89	1.41	12.89	1.61	12.06	1.26	11.78	3.04	.038	.73
Assembly	41.44	7.57	42.44	6.50	37.67	6.19	39.67	7.15	.004	.11
<i>Subjective Ratings</i>										
Stimulation	16.28	16.46	17.28	17.31	19.67	14.80	23.72	12.05	.21	.13
Sedation	9.17	11.26	8.89	12.47	25.39	14.24	21.78	11.96	.000	.21
Mental fatigue	18.33	25.29	19.28	22.64	47.72	25.57	33.11	27.27	.001	.093
Feel	2.11	3.83	16.83	26.63	65.67	21.55	59.33	25.12	.000	.40
Like	32.67	30.25	41.06	24.08	46.50	29.56	42.44	25.27	.39	.60
Impairment	6.17	23.45	7.89	15.69	57.67	24.76	48.50	23.94	.000	.38
Ability to drive	98.17	7.07	92.94	13.85	32.50	33.80	29.39	30.32	.000	.18
Subjective intoxication	0.03	0.12	0.28	0.49	3.53	1.59	3.28	1.36	.000	.99
Willing to pay	0.97	0.92	1.58	0.91	3.58	1.93	3.92	1.91	.000	.48

Note:

^a Dose effects on participants' pegboard trial data and subjective ratings were analyzed by separate 2 Sex (male vs. female) $\times$ 2 (Alcohol Dose: 0.65 g/kg vs. 0.0 g/kg) $\times$ 2 (Energy Drink: 3.57 ml/kg vs. 0.0 ml/kg) mixed design ANOVAs. See the text for results including Sex as a between subjects factor.