Experimental and Clinical Psychopharmacology
2010, Vol. 18, No. 6, 553–561

1064-1297/10/$12.00 DOI: 10.1037/a0021740

# Acute Effects of a Glucose Energy Drink on Behavioral Control

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There has been a dramatic rise in the consumption of glucose energy drinks (e.g., Amp, Monster, and Red Bull) in the past decade, particularly among high school and college students. However, little laboratory research has examined the acute objective and subjective effects of energy drinks. The purpose of this study was to investigate the acute effects of a glucose energy drink (Red Bull) on cognitive functioning. Participants ($N = 80$) were randomly assigned to one of five conditions: 1.8 ml/kg energy drink, 3.6 ml/kg energy drink, 5.4 ml/kg energy drink, placebo beverage, or no drink. Participants completed a well-validated behavioral control task (the cued go/no-go task) and subjective measures of stimulation, sedation, and mental fatigue both before and 30 minutes following beverage administration. The results indicated that compared with the placebo and no drink conditions, the energy drink doses decreased reaction times on the behavioral control task, increased subjective ratings of stimulation and decreased ratings of mental fatigue. Greatest improvements in reaction times and subjective measures were observed with the lowest dose and improvements diminished as the dose increased. The findings suggest that energy drink consumption can improve cognitive performance on a behavioral control task, potentially explaining the dramatic rise in popularity of these controversial new beverages.

*Keywords:* energy drink, behavioral control, reaction time, stimulation, mental fatigue

Since the 1997 debut of the glucose energy drink, Red Bull, in the United States, there has been a dramatic rise in energy drink consumption, especially in adolescents and young adults. The energy drink market grew over 400% between the years 2003 and 2007. Recent estimates value the international energy drink market at $4.8 billion (Mintel, 2008). Energy drinks are marketed as beverages that increase physical and mental performance, thus use has become widespread among active young people. The absence of regulatory oversight in the United States has resulted in aggressive marketing of energy drinks toward young people for psychoactive, performance-enhancing, and stimulant drug effects (Reissig, Strain, & Griffiths, 2009) and as a mixer with alcohol (Bryce & Dyer, 2007). Adverse health effects of energy drinks have led researchers to state that there are safety issues associated with the use of energy drinks, but this has had little impact on the increasing popularity of these beverages (Clauson, Shields, McQueen, & Persad, 2008). High school and college students have become particularly enamored with the use of these beverages. A survey of college students found that reasons for energy drink use included insufficient sleep, to increase energy in general, and to drink with alcohol while partying. Other reasons for drinking energy drinks were to assist in studying and while driving for extended periods of time (Malinauskas, Aeby, Overton, Carpenter-Aeby, & Barber-Heidal, 2007).

Energy drinks often contain a variety of ingredients including caffeine and other plant-based stimulants (e.g., guarana) and amino acids (e.g., taurine). Most researchers concur that caffeine seems to be the main compound that drives the stimulatory effects of these drinks (Ferreira, de Mello, Pompeia, & de Souaz-Formigoni, 2006; McCusker, Goldberger, & Cone, 2006). Caffeine content in energy drinks can range from a modest 50 mg to an alarming 505 mg per serving (bottle or can; Reissig et al., 2009). While the U.S. Food and Drug Administration (FDA) regulates the amount of caffeine found in sodas and other caffeinated drinks and foods, it does not regulate the amount of caffeine in energy drinks. Therefore, regulated foods and beverages can only contain a maximum of 65 mg of caffeine per serving, while a serving of energy drink could potentially contain up to 505 mg of caffeine. For example, Coca-Cola Classic contains only 2.9 mg of caffeine per fluid ounce, while Red Bull contains 9.6 mg of caffeine per fluid ounce (McCusker et al., 2006).

Current evidence suggests that moderate doses of caffeine positively affect cognitive performance. Several aspects of cognitive performance that show improvement under the influence of caffeine are attention, reaction time, visual search, psychomotor speed, memory, vigilance, and verbal reasoning (Childs & de Wit, 2008; Hewlett & Smith, 2006; Kennedy & Scholey, 2004; Scholey & Kennedy,

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This research was supported by a Faculty Fellowship from the Kentucky Biomedical Research Infrastructure Network (NIH Grant P20RR016481) and a Faculty Project Grant from Northern Kentucky University, both awarded to Cecile A. Marczinski, and a Summer Undergraduate Research Fellowship awarded to Meagan A. Howard by Northern Kentucky University.

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2004). Caffeine has also been shown to decrease mental fatigue (Kennedy & Scholey, 2004; Gershon, Shinar, & Ronen, 2009) and increase mood in states of fatigue (Childs & de Wit, 2008).

Since energy drinks are relatively new to the marketplace, there is limited laboratory evidence regarding energy drink effects on cognitive functioning. Moreover, scientists and physicians have raised concerns about the new trend of energy drinks being frequently mixed with alcoholic beverages by young drinkers in order to counteract the sedative effects of alcohol. This could be a potentially dangerous combination as drinkers sometimes report feeling less intoxicated when using energy drinks as mixers (Marczinski & Fillmore, 2006; Thombs et al., 2010). Despite the increase in use of energy drinks, their high caffeine content, and the current concerns with their use as alcoholic mixers, these beverages have not been widely studied, especially in controlled laboratory settings. Specifically, research examining the effects energy drinks have on behavioral control is lacking.

Behavioral control is the basic building block of all higher level cognitive processes such as memory and problem solving. A variety of theories postulate that two distinct processes govern behavioral control-one that activates behavior and one that inhibits behavior (Fowles, 1987; Gray, 1976, 1977; Logan & Cowan, 1984; Patternson & Newman, 1993; Quay, 1977). These two processes have also been called the go and stop processes (Clay, Allen, & Parran, 2008) or the hot and cold processes (Metcalfe & Mischel, 1999). It is thought that these two processes (activation and inhibition) act in opposition to one another, with the relative strength of each assumed to determine behavioral control. Deficient behavioral inhibition is inferred when behavior appears overactive, impulsive, and undercontrolled (Logan, Cowan, & Davis, 1984). Behavioral inhibition is of interest for a variety of reasons, including its role in disorders of failures of self-control, such as binge drinking and substance abuse (Fillmore, 2003).

Computerized tasks (e.g., the cued go/no-go task) have been developed to measure behavioral control. The cued go/no-go task examines the effect of preliminary information (i.e., cues) on the ability to quickly execute and suddenly suppress responses to subsequent go and stop signals. The task typically presents a stimulus cue followed by a go or no-go target that requires a response to be either executed (go) or suppressed (no-go). The cue provides information concerning the probability that a go or no-go target will be presented. The cue-target relationship is manipulated so that cues have a high probability of correctly signaling a target and a low probability of incorrectly signaling a target. Correct (i.e., valid) cues tend to facilitate response execution and response inhibition. For example, responses to go targets are faster when they are preceded by a go cue. Similarly, the likelihood of suppressing a response to a no-go target is greater when it is preceded by a no-go cue (Miller, Schaffer, & Hackley, 1991). The cue-supported facilitation of response execution and response suppression is attributed to advance preparatory processing that occurs while processing the cue and before the target actually appears. Once the target appears, less processing of the appropriate response is required (Duncan, 1981; Posner, 1980; Posner, Snyder, & Davidson, 1980). When a cue incorrectly predicts the target, the execution or inhibition of a response is difficult since none of the advanced preparatory processing was appropriate for the given target. The challenging invalid cue condition is often deleteriously impaired by drugs that slow information processing (Marczinski & Fillmore, 2003a, 2003b).

Behavioral control is an important cognitive process to measure in a study of the effects of energy drinks. Cued go/no-go tasks have been used previously to study the effects of various stimulant drugs such as caffeine and *d*-amphetamine (Fillmore et al., 2003; Marczinski & Fillmore, 2003a). The findings regarding the effects of different stimulants on behavioral control have been variable. For example, Marczinski and Fillmore (2003a) found that moderate doses of caffeine (2–4 mg/kg) improved response execution on cued go/no-go task performance but these doses of caffeine did not change response inhibition. By contrast, oral doses of *d*-amphetamine (5–20 mg) impaired response inhibition on cued go/no-go task performance but these doses did not change response execution. Therefore, the cued go/no-go task is an appropriate task for measuring behavioral control under the effects of energy drinks. Given the significant caffeine content in energy drinks, it is plausible that the stimulant action of energy drinks could improve or impair behavioral control.

Beyond the importance of understanding how these frequently consumed energy drink beverages impact behavioral control in young adults, additional concerns regarding energy drinks have emerged. In a recent study, responses by college students on a questionnaire revealed that frequency of energy drink consumption has been found to be positively associated with risk-taking, fighting, drinking problems, drug use, and other problem behaviors. This led the author of this study to propose that college students who use energy drinks more often also seem to have poor impulse control (Miller, 2008). Are these young energy drink consumers attempting to compensate for their lack of behavioral control by consuming energy drinks or are the acute effects of energy drinks leading to disinhibition? To answer these questions, we set out to examine the acute effects of energy drinks in a controlled laboratory study, with behavioral control as the cognitive process of interest.

In the present study, we examined the effects of three different doses of the most popular energy drink, Red Bull, on behavioral control. College students were randomly assigned to one of five conditions (no drink, placebo beverage, 1.8 ml/kg, 3.6 ml/kg, or 5.4 ml/kg Red Bull). Behavioral control was measured with the cued go/no-go task. In addition to examining the effects of the beverages on behavioral control, the study also examined how the different doses of energy drink affected drinkers' subjective reports of stimulation, sedation, and mental fatigue. We hypothesized that the energy drink doses would improve response execution in the behavioral control task and would improve subjective reports of stimulation and decrease mental fatigue.

## Method

### Participants

Eighty adults (34 men and 46 women) between the ages of 18 and 40 (mean age = 20.1 year, *SD* = 3.1) participated in this study. The self-reported racial-ethnic make-up of the sample included 6 African American, 1 Hispanic and 73 Caucasian participants. Potential volunteers completed questionnaires that provided demographic information and physical and mental health status. Individuals with a self-reported psychiatric disorder, substance abuse disorder, head trauma, or other injury of the central nervous system were excluded from the study. No women who were pregnant or breast-feeding, as determined by self-report, participated in this research. To be eligible to participate, participants had to be 18 years old, have consumed at least one energy drink in the past year, and have consumed at least one caffeinated beverage in the past two 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. Participants were recruited by means of an introductory psychology course at Northern Kentucky University and received partial course credit for their participation. All volunteers provided informed consent prior to participating and the Northern Kentucky University Institutional Review Board approved this study.

### Materials and Procedure

**Caffeine Use Questionnaire (CUQ).** This questionnaire provides a measure of a participant's daily caffeine consumption in milligrams per kilogram of body weight. The questionnaire asks the participant to report their typical daily consumption of beverages (e.g., coffee, tea, soft drinks, energy drinks) and foods (e.g., chocolate) containing caffeine. Estimates of the caffeine content in foods and beverages were taken from Barone and Roberts (1996) and manufacturer websites for newer products.

**Eysenck impulsiveness questionnaire (Eysenck, Pearson, Easting, & Allsop, 1985).** This 19-item questionnaire assesses impulsiveness by posing yes-no questions. This scale ranges from 0–19 with higher scores indicating greater self-reported impulsiveness. Participants indicate their response by circling the appropriate answer.

**Barratt Impulsiveness Scale-11 (BIS-11; Patton, Stanford, & Barratt, 1995).** This 30-item questionnaire asks participants to rate how typical different statements are for them. Participants respond on a 4-point Likert scale ranging from *Rarely/Never* to *Almost Always/Always*. Higher scores indicate greater impulsivity.

**ADD/H adolescent self-report scale – Short form (Robin & Vandermay, 1996).** This 11-item questionnaire assesses various problems related to attention (concentration, distraction). Respondents endorse each item on a 4-point Likert-type scale from 0 (*not at all*) to 3 (*very much*). Higher scores indicate greater attention problems.

**Biphasic Alcohol Effects Scale (BAES; Martin, Earleywine, Musty, Perrine, & Swift, 1993).** This is a 14-adjective rating scale asking participants to provide subjective ratings of their level of stimulation and sedation after consuming a beverage. Seven adjectives describe stimulation effects (e.g., stimulated, elated) while the remaining seven describe sedation effects (e.g., sedated, sluggish). Participants rate the degree to which dose administration produces each effect on a 11-point Likert-type scale ranging from 0 (*not at all*) to 10 (*extremely*). The Stimulation and Sedation scores were summed separately to provide a total subscale score for Stimulation and Sedation (score subscale range = 0–70).

**Mental fatigue rating scale (Beirness, 1987).** This 1-item visual analogue scale asks subjects to rate their overall level of mental fatigue at the time of the rating. Subjects indicate their response ranging from "*not at all*" to "*very much*" by placing a vertical mark through a 100-mm line.

**Cued go/no-go task.** The acute objective effects of the energy drink were measured by the cued go/no-go task, a neurocognitive task that measures behavioral control mechanisms (Marczinski & Fillmore, 2003a, 2003b, 2005; Marczinski, Combs, & Fillmore, 2007). This task requires participants to make quick responses to go targets and to suppress responses to no-go targets. The go and no-go targets are colored green and blue rectangles, respectively. Participants are instructed to make a response by pressing a forward slash (/) key as soon as a go (green) target appears and to not make any response when a no-go (blue) target is presented. A trial involves the following sequence of events: 1) a fixation point (+) for 800 ms; 2) a blank screen for 500 ms; 3) a cue, displayed for one of five stimulus onset asynchronies (SOAs = 100, 200, 300, 400 and 500 ms); 4) a go or no-go target, visible until a response occurs or 1000 ms elapses; and 5) an intertrial interval of 700 ms. The cue is a rectangle presented in the center of the computer display in either a horizontal (height = 2.5 cm, width = 7.5 cm) or vertical (height = 7.5 cm, width = 2.5 cm) orientation. The go and no-go targets, green and blue, are displayed as a solid hue that fills the interior of the rectangle cue. The go and no-go targets are presented in hues that are easily distinguishable.

The orientation of the cue (horizontal or vertical) signals the probability that a go or no-go target will be displayed inside the cue. Cues presented vertically precede the go target on 80% of the trials and precede the no-go target on 20% of the trials. Cues presented horizontally precede the no-go target on 80% of the trials and precede the go target on 20% of the trials. Based on cue-target pairings, vertical and horizontal cues operate as go and no-go cues, respectively. The different SOAs (100, 200, 300, 400, and 500 ms) between cues and targets encourage subjects to pay attention to the cues and the variability and randomness of the SOAs prevent subjects from anticipating the exact onset of the targets.

A cued go/no-go test consists of 500 trials that present the four possible cue-target combinations. An equal number of vertical (250) and horizontal (250) cues are presented before an equal number of go (250) and no-go (250) target stimuli. Each cue-target combination is presented at each of the five SOAs, with an equal number of SOAs separating each cue-target combination. The presentation of cue-target combinations and SOAs is random. For each trial, the computer records whether or not a response occurred and if a response was made, the reaction time (RT) in milliseconds is measured from the onset of the target until the key is pressed. To encourage fast and accurate responding, feedback is presented during the intertrial interval by displaying the words "correct" or "incorrect" along with the reaction time in milliseconds. A test takes most participants approximately 25 minutes to complete which includes four separate one minute rest periods during the task. The task is operated by E-Prime experiment generation software (Schneider, Eschman, & Zuccolotto, 2002).

## Procedure

Individuals viewed web-based announcements describing this study and signed up for participation for partial course credit for an introductory psychology course through a web-based portal (nku.sona-systems.com). Volunteers were informed that the purpose of the experiment was to study the effects of energy drinks on behavioral and mental functioning. Volunteers were told that they would be asked to perform computerized tasks and complete questionnaires. Moreover, they were informed that they may or may not receive a beverage to consume. If a beverage was given, it could contain the maximum dose of caffeine found in a cup of coffee or 2 cans of a soft drink.

Sessions were conducted in the Psychology department laboratories and began between 10 a.m. and 6 p.m. Prior to the 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. Participants who failed to follow these instructions were rescheduled for another session time. Participants were tested individually by a research assistant. All testing was conducted in a small room that consisted of a chair and a desk with the computer that operated the cued go/no-go task.

Upon entering the laboratory, participants were randomly assigned to one of five dose conditions (1.8 ml/kg energy drink, 3.6 ml/kg energy drink, 5.4 ml/kg energy drink, 3.6 ml/kg placebo drink, or no drink). Participants provided informed consent, were weighed and completed questionnaires. The questionnaires included a basic medical history form, the CUQ, Eysenck impulsiveness questionnaire, the BIS-11 and the ADD/H questionnaire. Participants then performed a baseline test on the cued go/no-go task. Participants were instructed to press the forward slash key (/) on the keyboard as quickly as possible whenever a green (i.e., go) target appeared and to suppress the response whenever a blue (i.e., no-go) target appeared. The computer displayed how fast a participant responded to each go target by presenting the milliseconds required from target onset until the key was pressed. Participants were encouraged to make fast responses (i.e., in the fewest milliseconds) while remaining accurate (i.e., not pressing the key when a no-go target appeared). Upon completion of the cued go/no-go task, participants completed the baseline measurements of BAES and mental fatigue ratings.

Participants were then given their beverage (if assigned). However, the exact contents of the beverages were never disclosed to participants in this study. Red Bull was chosen as the energy drink beverage as it is the most commonly purchased energy drink in the U.S. market. 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 in pilot studies in our laboratory. Doses were calculated on the basis of body weight. The 1.8 ml/kg, 3.6 ml/kg and 5.4 ml/kg energy drink doses were chosen as they are the equivalent of 0.5, 1 and 1.5 250 ml cans of energy drink for a typical 70 kg individual. For reference, 1 can of Red Bull (250 ml) contains 76 mg of caffeine. Thus, for our average 78 kg participant, the amount of caffeine consumed in the 1.8 ml/kg, 3.6 ml/kg, and 5.4 ml/kg energy drink conditions was 45.6 mg, 91.2 mg, and 136.7 mg of caffeine, respectively. The placebo dose consisted of decaffeinated soft drink in the amount of the medium energy drink dose (3.6 ml/kg). For the 3.6 ml/kg dose condition, the placebo and energy drink were relatively well matched in terms of calories and glucose content. For our average 78 kg participant, the placebo dose consisted of 29.3 g sugars and the 3.6 ml/kg energy drink dose consisted of 30.8 g sugars. In all cases, the beverage was served in a plastic cup and participants were asked to consume their beverage within 6 minutes. After dose administration, participants relaxed and read magazines.

Participants' cued go/no-go task performance was tested at 30 minutes after drinking began. Thus, the test occurred during the ascending period when caffeine is most active. After the test (55 minutes after drinking began), participants completed the BAES and the mental fatigue rating scales. Upon session completion, participants were debriefed and released.

## Criterion Measures and Data Analyses

The two primary measures of interest from the cued go/no-go task were the participants' change in speed of responding to go targets (response execution) from baseline to postdrink test and participants' change in failures to inhibit responses to no-go targets (failures of response inhibition) from baseline to postdrink test.

**Response execution.** Response execution was measured by the RT to go targets. Smaller RTs indicated greater facilitation of response execution. A mean RT score for each participant was calculated for each cue condition (go and no-go) on a test. Responses with RTs less than 100 ms were excluded. These outliers were infrequent, occurring on average on less that 0.01% of the trials for which a response was observed (i.e., less than one trial per test). Baseline scores for the different dose conditions were analyzed by separate one-way ANOVAs, separately for each cue condition (i.e., valid go cue and invalid no-go cue). In past research, the invalid cue condition is most amenable to drug-induced changes, such as the acute administration of alcohol or caffeine (Marczinski & Fillmore, 2003a, 2003b, 2005; Marczinski et al., 2007). Change scores were calculated by subtracting the mean RT for the baseline test from the postbeverage mean RT for each subject and for each cue condition. Change scores in response execution were analyzed by a one-way ANOVA. Multiple comparisons of RTs for each dose condition utilized least significant difference (LSD) tests.

**Failures of response inhibition.** Failures of response inhibition were measured as the proportion (p) of no-go targets in which a participant failed to inhibit a response. These p-inhibition failure scores were calculated for each cue condition (go and no-go) on a test. Baseline scores for the different dose conditions were analyzed by one-way ANOVAs, separately for each cue condition (i.e., valid no-go cue and invalid go cue). In past research, the invalid cue condition measures prepotent (i.e., instigated) responding and is most amenable to drug-induced changes (Marczinski & Fillmore, 2003a, 2003b, 2005; Marczinski et al., 2007). Change scores were calculated by subtracting the mean p-inhibition failure score for the baseline test from the postbeverage p-inhibition failure score for each subject and for each cue condition. Change scores in failures of response inhibition were analyzed by a one-way ANOVA. Multiple comparisons of p-inhibition failure scores for each condition utilized LSD tests. The alpha level was set at .05 for all statistical tests and SPSS 17.0 was used to conduct all analyses.

## Results

### Demographic Characteristics, Self-Reported Caffeine Use, and Baseline Measures

Table 1 lists all demographic, questionnaire and baseline measures for participants in all five groups. Results of chi-square tests revealed no significant differences in gender distribution or self-reported race/ethnicity among the groups, *p*s $>$ .26. Results of one-way ANOVAs for each demographic, caffeine use, subjective effects and cued go/no-go task baseline measures revealed no significant differences among the groups, *p*s $>$ .11. The sample reported a mean (*SD*) daily caffeine use of 4.5 (7.6) mg/kg. For the average 80 kg participant in this study, this caffeine would approximate 2 cups of coffee (Barone & Roberts, 1984). All subsequent analyses of subjective ratings and cued go/no-go task performance were performed with self-reported caffeine use as a covariate. However, no significant main effects or interactions with caffeine use were found and all analyses are reported without the covariate results.

### Subjective Ratings

Since a main interest was in examining the effects of the energy drink doses on each of the subjective ratings (stimulation, sedation, mental fatigue), we created difference scores for each rating that controlled for the participants' baseline state (e.g., subtracting the stimulation rating post-drink from the baseline stimulation rating). Results of a one-way ANOVA for change scores in stimulation ratings revealed a significant effect of group, $F(4, 75) = 3.22$, mean standard error (*MSE*) = 174.01, $p = .02$. Post hoc tests revealed that stimulation change scores were significantly higher in the 1.8 ml/kg energy drink condition compared to the no-drink condition ($p = .01$), and significantly higher in the 1.8 ml/kg and 5.4 ml/kg energy drink conditions compared to placebo, *p*s $<$ .02. Figure 1 illustrates how the 1.8

Table 1
*Demographic Characteristics, Self-Reported Caffeine Use and Baseline Measures*

| | Dose Condition | | | | | |
|---|---|---|---|---|---|---|
| | No drink *M* (*SD*) | Placebo *M* (*SD*) | 1.8 ml/kg energy drink *M* (*SD*) | 3.6 ml/kg energy drink *M* (*SD*) | 5.4 ml/kg energy drink *M* (*SD*) | Significance |
| Age | 21.6 (5.1) | 19.6 (2.2) | 19.8 (2.8) | 20.4 (2.3) | 18.8 (1.0) | *ns* |
| Gender (M:F) | 7:9 | 7:9 | 7:9 | 7:9 | 6:10 | *ns* |
| Weight (kg) | 79.9 (30.1) | 77.9 (21.8) | 82.9 (29.1) | 75.8 (21.8) | 73.5 (11.5) | *ns* |
| Body Mass Index | 26.4 (6.8) | 26.9 (8.2) | 28.1 (7.4) | 25.6 (5.7) | 25.6 (3.7) | *ns* |
| Self-reported caffeine use (mg/kg) | 4.3 (5.0) | 7.1 (15.5) | 4.1 (4.3) | 3.2 (2.5) | 3.8 (2.1) | *ns* |
| Eysenck | 8.3 (3.6) | 7.5 (3.2) | 7.7 (4.6) | 8.0 (5.0) | 7.9 (4.5) | *ns* |
| BIS-11 total | 59.4 (8.9) | 58.0 (10.0) | 55.9 (12.7) | 56.6 (9.7) | 55.6 (8.6) | *ns* |
| Attention subscore | 8.6 (2.2) | 8.4 (2.6) | 7.6 (2.1) | 7.6 (1.9) | 7.3 (1.4) | *ns* |
| Motor subscore | 17.3 (3.3) | 17.6 (2.7) | 15.3 (3.7) | 16.8 (2.8) | 16.2 (2.6) | *ns* |
| Self control subscore | 13.8 (3.5) | 13.1 (3.7) | 13.3 (4.0) | 12.9 (3.4) | 13.3 (3.7) | *ns* |
| Cognitive complexity | 7.6 (2.1) | 7.2 (2.3) | 7.4 (1.9) | 7.2 (1.4) | 7.6 (1.1) | *ns* |
| Perseveration | 5.3 (1.3) | 5.9 (2.3) | 6.3 (2.3) | 5.5 (1.6) | 5.6 (1.4) | *ns* |
| Cognitive instability | 6.9 (1.7) | 5.9 (1.6) | 6.1 (2.2) | 6.5 (1.3) | 5.6 (1.4) | *ns* |
| ADD/H total score | 16.3 (6.2) | 13.0 (4.9) | 12.3 (6.5) | 12.6 (7.0) | 12.5 (7.8) | *ns* |
| Sedation rating | 22.3 (14.0) | 18.6 (16.7) | 19.6 (17.0) | 20.2 (14.2) | 17.4 (13.0) | *ns* |
| Stimulation rating | 23.3 (12.9) | 29.6 (15.6) | 22.8 (14.8) | 23.7 (15.1) | 21.9 (13.4) | *ns* |
| Mental fatigue rating | 48.6 (23.6) | 41.2 (27.6) | 53.5 (28.5) | 41.3 (27.0) | 36.6 (23.9) | *ns* |
| RT (ms) valid go cue | 287.6 (23.1) | 280.5 (28.6) | 284.8 (21.8) | 284.2 (25.4) | 292.6 (27.9) | *ns* |
| RT (ms) invalid no-go cue | 296.8 (23.3) | 299.0 (28.4) | 303.0 (24.9) | 299.7 (29.8) | 310.0 (25.7) | *ns* |
| p-inhibition failures valid no-go cue | .04 (.03) | .06 (.05) | .03 (.03) | .03 (.03) | .04 (.04) | *ns* |
| p-inhibition failures invalid go cue | .09 (.11) | .10 (.07) | .11 (.11) | .05 (.06) | .09 (.10) | *ns* |


*Figure 1.* Mean difference scores representing the stimulation rating postdrink subtracted from the stimulation rating at baseline for each dose condition. Standard errors are represented in the figure by the error bars attached to each column. * indicates a significant difference from the no drink condition and ˆ indicates a significant difference from the placebo condition.

ml/kg and 5.4 ml/kg energy drink dose conditions resulted in participants reporting that they felt more stimulated compared to baseline.

Results of a one-way ANOVA for change scores in mental fatigue ratings revealed a significant effect of group, $F(4, 75) = 4.90$, $MSE = 746.94$, $p = .001$. Post hoc tests revealed that mental fatigue change scores were significantly lower in the 1.8 ml/kg, 3.6 ml/kg, and 5.4 ml/kg energy drink conditions compared to both the no drink and placebo conditions, $p$s $< .05$. Figure 2 reveals how all three energy drink dose conditions results in participants reporting that they felt less fatigued compared to baseline. Finally, there was no significant result of a one-way ANOVA for change in sedation rating, $p > .10$.

### Cued Go/No-Go Task Performance

Results of a one-way ANOVA for a change in mean RTs following invalid (no-go) cues revealed a significant effect of group, $F(4, 75) = 2.95$, $MSE = 436.98$, $p = .03$. Post hoc tests revealed that mean changes in RT were significantly faster in the 1.8 ml/kg, 3.6 ml/kg, and 5.4 ml/kg energy drink conditions compared to the placebo condition, $p$s $<.03$. In addition, mean changes in RT were significantly faster in the 1.8 ml/kg energy drink condition compared to the no drink condition, $p = .04$. Figure 3 reveals how performance on the cued go/no-go task was faster following invalid cues under the three energy drink conditions compared to baseline. By contrast, the no drink and placebo conditions exhibited slower response times compared to baseline.

Results of a one-way ANOVA for change in mean RTs following valid (go) cues indicated a nonsignificant trend for the effect of group, $p = .08$. While not significant, the pattern of results followed those seen with RTs for the invalid (no-go) cue condition as responses were faster under the three energy drink conditions compared to baseline and response times were slower in the no drink and placebo conditions compared to baseline. There were no significant effects for the one-way ANOVAs for changes in p-inhibitory failures following valid (no-go) and invalid (no-go) cues, $p$s $> .43$.

## Discussion

This research examined the acute effects of a glucose energy drink (1.8 ml/kg, 3.6 ml/kg, and 5.4 ml/kg Red Bull) on both subjective and objective measures of performance. The results showed that the energy drink increased self-reported ratings of stimulation and decreased self-reported ratings of mental fatigue. In addition, the energy drink decreased RTs, a measure of response execution in the cued go/no-go task (a task commonly used to measure behavioral control). The energy drink had no effect on response inhibition in the same task. Together, the research findings

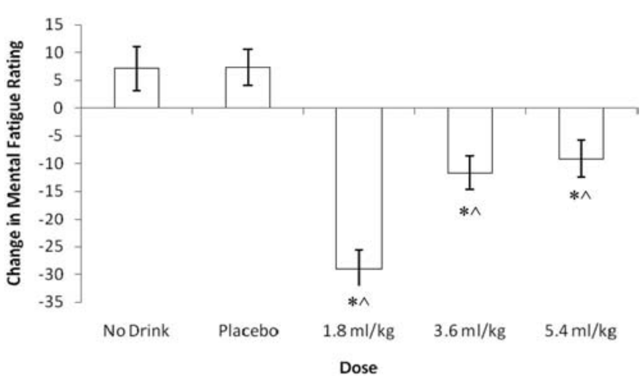


*Figure 2.* Mean difference scores representing the mental fatigue rating postdrink subtracted from the mental fatigue rating at baseline for each dose condition. Standard errors are represented in the figure by the error bars attached to each column. * indicates a significant difference from the no drink condition and ˆ indicates a significant difference from the placebo condition.

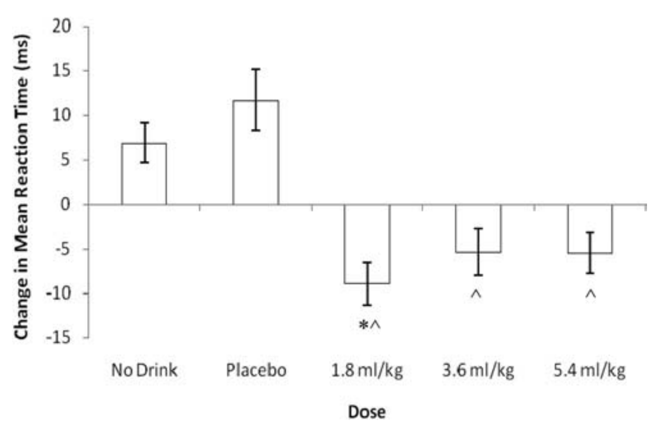


*Figure 3.* Mean difference scores representing the mean reaction time to go target postdrink subtracted from the mean reaction time (ms) to the go target at baseline following invalid (no-go cues) for each dose condition. Standard errors are represented in the figure by the error bars attached to each column. * indicates a significant difference from the no drink condition and ˆ indicates a significant difference from the placebo condition.

reveal that acute administration of a popular energy drink resulted in stimulant-like effects on both subjective and objective measures.

The results are consistent with other studies that have demonstrated that the acute effects of energy drinks and caffeine lead to subjective reductions in mental fatigue and improvements in cognitive performance such as decreased reaction times (Alford, Cox & Wescott, 2001; Gershon et al., 2009; Hewlett & Smith, 2006; Kennedy & Scholey, 2004; Seidl, Peyrl, Nicham, & Hauser, 2000; Warburton & Bersellini, 2001). However, not all studies have observed improvements in cognition when energy drinks are administered. For example, Curry and Stasio (2009) had college students consume another popular energy drink, Monster, and then complete the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) at 45 minutes following the onset of dose administration. While the authors did not correct for body weight difference in dose administration, the dose of energy drink was similar to the 5.4 ml/kg dose used in the current study. Curry and Stasio (2009) reported that the energy drink did not result in any statistically significant changes in posttest performance for any of the measures, including immediate memory, visuospatial skills, language, attention, or delayed memory. Thus, it may be possible that some cognitive functions improve with energy drink administration, yet other aspects of cognition remain unchanged. In the current study, response inhibition was not changed by dose administration despite improvements in reaction times, consistent with this idea. Alternatively, it may be that not all energy drinks result in similar effects. This seems less likely given that Monster contains many similar ingredients to Red Bull, including high levels of caffeine.

However, it is important to note that there is some controversy in the literature regarding the improvements in cognitive performance by caffeine being due mainly to the reversal of caffeine withdrawal effects in caffeine-deprived participants (Childs & de Wit, 2008; James, 1994; James & Keane, 2007), In the current study, the subjects had only limited caffeine deprivation (i.e., 8 hours) and did not report any significant symptoms of caffeine withdrawal (such as headaches and caffeine craving). However, participants in the Curry and Stasio (2009) study refrained from caffeine only 1 hour prior to arriving in the laboratory. Thus, it remains somewhat uncertain if improvements in subjective state and reaction times on the behavioral task in the current study reflect reversal of withdrawal effects. It seems less likely given that the participants had a limited period of time that they needed to refrain from use of caffeine, they did not report any caffeine withdrawal symptoms (e.g., headache, caffeine craving) and they were moderate consumers of caffeine, consuming the equivalent quantity of caffeine found in two cups of coffee daily.

Energy drinks are often used to ameliorate fatigue and boredom. A recent survey of college students found that often cited reasons for energy drink use were to counteract insufficient sleep and to assist in studying (Malinauskas et al., 2007). In the current study, participants did not report excessive fatigue. The findings of the benefit of the energy drink may have been even more pronounced if we had tested subjects who had been sleep-deprived or had given the subjects tasks that involved extended periods of cognitive demand. Previous laboratory studies have noted that the effects of caffeine and energy drinks on improvements in subjects state and performance deficits were most pronounced in fatigued individuals (Childs & de Wit, 2008; Kennedy & Scholey, 2004).

In the literature, there have been suggestions that energy drink consumption rates are high in young individuals, particularly males, who exhibit impulse control problems, such as illicit drug use and other disinhibited behaviors such as fighting (Miller, 2008). This has led others to suggest that energy drinks may serve as a gateway to other forms of drug dependence (Reissig et al., 2009). However, there may be an alternative explanation as to why individuals with poor impulse control who use other drugs may consume large amounts of energy drinks. It is possible that individuals with poor impulse control may be attracted to the consumption of energy drinks in an attempt to compensate for a lack of behavioral control. In the current study, energy drinks were found to improve one aspect of behavioral control (response execution as measured in reaction time) but not the other aspect of behavioral control (response inhibition). Future individual differences studies including individuals with poor impulse control are needed to further examine how energy drinks alters behavioral control.

The results of this study may be used in the future in designing studies measuring the effects of alcohol mixed with energy drinks on behavioral control. Mixing alcohol with energy drinks has become a popular and possibly hazardous practice among young social drinkers (Malinauskas et al., 2007; O'Brien, McCoy, Rhodes, Wagoner, & Wolfson, 2008; Oteri, Francesco, Caputi, & Calapai, 2007). College students who use alcohol with energy drinks tend to drink more and have more alcohol-related consequences compared to the consumption of alcohol alone (Price, Hilchey, Darredeau, Fulton, & Barrett, 2010; Thombs et al., 2010). The results of the current study illustrate that energy drinks can increase stimulation and decrease mental fatigue, suggesting that they may be used with alcohol to counteract the sedation associated with drinking.

There were several limitations to this study. First, only one energy drink was used for this study and the constituent components can differ dramatically among brands. Red Bull does gross the highest sales in the energy drink market in the United States (65% of market share in 2005), which is why it was chosen (Bryce & Dyer, 2007). Future studies should examine the variety of different energy drinks to determine the importance of caffeine, glucose and the other ingredients in the effects observed in participants. A second limitation of the current study is that participants were blind to what they were receiving (energy drink vs. placebo). However, expectation is known to play a critical role in how participants display behavioral improvement or impairment in response to caffeine (Fillmore, Mulvihill, & Vogel-Sprott, 1994; Fillmore, Roach, & Rice, 2002; Fillmore & Vogel-Sprott, 1992). Therefore, future studies should examine the role of expectation in response to energy drinks. A third limitation of the current study is that only doses of energy drink ranging from 1.8 to 5.4 ml/kg (up to 1.5 cans for a typical participant) were tested. As improvements in reaction times and feelings of mental fatigue and stimulation were most evident at the lowest dose, testing beyond the current dose range might better illustrate how "less is more" when it comes to energy drinks. This finding would be consistent with the existing literature with caffeine and other stimulants that performance improves in an inverted-U shape fashion. As a dose rises too high, performance deteriorates (Smith, 2002). Future studies should examine doses outside the range reported in this study.

In summary, the results of this study indicate that consumption of the glucose energy drink, Red Bull, can increase feelings of stimulation, decrease mental fatigue, and decrease reaction times on a behavioral control task. The energy drink did not appear to alter response inhibition on the same task. This finding is of interest given that energy drinks are frequently mixed with alcohol and the acute effects of alcohol impair response inhibition. Since regulation of energy drinks is lax in the United States in regard to content labeling and possible health warnings, especially when mixed with alcohol, having a better understanding of the acute subjective and objective effects of these beverages is warranted.

## References


Alford, C., Cox, H., & Wescott, R. (2001). The effects of red bull energy drink on human performance and mood. *Amino Acids, 21,* 139–150.

Barone, J. J., & Roberts, H. R. (1984). Human consumption of caffeine. In P. B. Dews (Ed.), *Caffeine: Perspectives from recent research* (pp. 59–73). Berlin: Springer-Verlag.

Barone, J. J., & Roberts, H. R. (1996). Caffeine consumption. *Food and Chemical Toxicology, 34,* 119–129.

Beirness, D. J. (1987). Self-estimates of blood alcohol concentration in drinking-driving context. *Drug and Alcohol Dependence, 19,* 79–90.

Bryce, D. J., & Dyer, J. H. (2007). Strategies to crack well-guarded markets. *Harvard Business Review, 85,* 84–92.

Childs, E., & de Wit, H. (2008). Enhanced mood and psychomotor performance by a caffeine- containing energy capsule in fatigued individuals. *Experimental and Clinical Psychopharmacology, 16,* 13–21.

Clauson, K. A., Shields, K. M., McQueen, C. E., & Persad, N. (2008). Safety issues associated with commercially available energy drinks. *Journal of the American Pharmacy Association, 48,* e55–e63.

Clay, S. W., Allen, J., & Parran, T. (2008). A review of addiction. *Postgraduate Medicine, 120,* E01–E07.

Curry, K., & Stasio, M. J. (2009). The effects of energy drinks alone and with alcohol on neuropsychological functioning. *Human Psychopharmacology Clinical and Experimental, 24,* 473–481.

Duncan, J. (1981). Directing attention in the visual field. *Perception and Psychophysics, 30,* 90–93.

Eysenck, S. B. G., Pearson, P. R., Easting, G., & Allsop, J. F. (1985). Age norms for impulsiveness, venturesomeness and empathy in adults. *Personality and Individual Differences, 6,* 613–619.

Ferreira, S. E., de Mello, M. T., Pompeia, S., & de Souza-Formigoni, M. L. O. (2006). Effects of energy drink ingestion on alcohol intoxication. *Alcoholism: Clinical and Experimental Research, 30,* 598–605.

Fillmore, M. T. (2003). Drug abuse as a problem of impaired control: Current approaches and findings. *Behavioral and Cognitive Neuroscience Reviews, 2,* 179–197.

Fillmore, M. T., Mulvihill, L. E., & Vogel-Sprott, M. (1994). The expected drug and its expected effect interact to determine placebo responses to alcohol and caffeine. *Psychopharmacology, 115,* 383–388.

Fillmore, M. T., Roach, E. L., & Rice, J. T. (2002). Does caffeine counteract alcohol-induced impairment? The ironic effects of expectancy. *Journal of Studies on Alcohol, 63,* 745–754.

Fillmore, M. T., Rush, C. R., & Marczinski, C. A. (2003). Effects of *d*-amphetamine on behavioral control in stimulant abusers: The role of prepotent response tendencies. *Drug and Alcohol Dependence, 71,* 143–152.

Fillmore, M. T., & Vogel-Sprott, M. (1992). Expected effect of caffeine on motor performance predicts the type of response to placebo. *Psychopharmacology, 106,* 209–214.

Fowles, D. C. (1987). Application of a behavioral theory of motivation to the concepts of anxiety and impulsivity. *Journal of Research on Personality, 21,* 417–435.

Gershon, P., Shinar, D., & Ronen, A. (2009). Evaluation of experience-based fatigue countermeasures. *Accident Analysis and Prevention, 41,* 969–975.

Gray, J. A. (1976). The behavioral inhibition system: A possible substrate for anxiety. In M. P. Feldman & A. Broadhurst (Eds.), *Theoretical and experimental bases of behavior therapies* (pp. 3–41). London: Wiley.

Gray, J. A. (1977). Drug effects of fear and frustration. Possible limbic site of action of minor tranquilizers. In L. L. Iverson, S. D. Iverson, & S. H. Synder (Eds.), *Handbook of psychopharmacology* (Vol. 8, pp. 433–529). New York: Plenum Press.

Hewlett, P., & Smith, A. (2006). Acute effects of caffeine in volunteers with different patterns of regular consumption. *Human Psychopharmacology: Clinical and Experimental, 21,* 167–180.

James, J. E. (1994). Does caffeine enhance of merely restore degraded psychomotor performance? *Neuropsychobiology, 30,* 124–125.

James, J. E., & Keane, M. A. (2007). Caffeine, sleep and wakefulness: Implications of new understanding about withdrawal reversal. *Human Psychopharmacology: Clinical and Experimental, 22,* 549–558.

Kennedy, D. O., & Scholey, A. B. (2004). A glucose-caffeine "energy drink" ameliorates subjective and performance deficits during prolonged cognitive demand. *Appetite, 42,* 331–333.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review, 91,* 295–327.

Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: A model and a method. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 276–291.

Malinauskas, B. M., Aeby, V. G., Overton, R. F., Carpenter-Aeby, T., & Barber-Heidal, K. (2007). A survey of energy drink consumption patterns among college students. *Nutrition Journal, 6,* 35.

Marczinski, C. A., Combs, S. W., & Fillmore, M. T. (2007). Increased sensitivity to the disinhibiting effects of alcohol in binge drinkers. *Psychology of Addictive Behaviors, 21,* 346–354.

Marczinski, C. A., & Fillmore, M. T. (2003a). Dissociative antagonistic effects of caffeine on alcohol-induced impairment of behavioral control. *Experimental and Clinical Psychopharmacology, 11,* 228–236.

Marczinski, C. A., & Fillmore, M. T. (2003b). Preresponse cues reduce the impairing effects of alcohol on the execution and suppression of responses. *Experimental and Clinical Psychopharmacology, 11,* 110–117.

Marczinski, C. A., & Fillmore, M. T. (2005). Alcohol increases reliance on cues that signal acts of control. *Experimental and Clinical Psychopharmacology, 13,* 15–24.

Marczinski, C. A., & Fillmore, M. T. (2006). Clubgoers and their trendy cocktails: Implications of mixing caffeine into alcohol on information processing and subjective reports of intoxication. *Experimental and Clinical Psychopharmacology, 14,* 450–458.

Martin, C. S., Earleywine, M., Musty, R. E., Perrine, M. W., & Swift, R. M. (1993). Development and validation of the Biphasic Alcohol Effects Scale. *Alcoholism: Clinical and Experimental Research, 17,* 140–146.

McCusker, R. R., Goldberger, B. A., & Cone, E. J. (2006). Caffeine content of energy drinks, carbonated sodas, and other beverages. *Journal of Analytical Toxicology, 30,* 112–114.

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review, 106,* 3–19.

Miller, J., Schaffer, R., & Hackley, S. A. (1991). Effects of preliminary information in a go versus no-go task. *Acta Psychologica, 76,* 241–292.

Miller, K. E. (2008). Energy drinks, race, and problem behaviors among college students. *Journal of Adolescent Health, 43,* 490–497.

Mintel. (2008). *Energy drink explosion hits food.* Press release retrieved from www.mintel.com

O'Brien, M. C., McCoy, T. P., Rhodes, S. D., Wagoner, A., & Wolfson, M. (2008). Caffeinated cocktails: Energy drink consumption, high-risk drinking, and alcohol-related consequences among college students. *Academic Emergency Medicine, 15,* 453–460.

Oteri, A., Francesco, S., Caputi, A. P., & Calapai, G. (2007). Intake of energy drinks in association with alcoholic beverages in a cohort of students of the School of Medicine of the University of Messina. *Alcoholism: Clinical and Experimental Research, 31,* 1677–1680.

Patterson, C. M., & Newman, J. P. (1993). Reflectivity and learning from aversive events: Toward a psychological mechanism for the syndromes of disinhibition. *Psychological Review, 100,* 716–736.

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51,* 768–774.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3–25.

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology, 109,* 160–174.

Price, S. R., Hilchey, C. A., Darredeau, C., Fulton, H. G., & Barrett, S. P. (2010). Energy drink coadministration is associated with increased reported alcohol ingestion. *Drug and Alcohol Review, 29,* 331–333.

Quay, H. C. (1997). Inhibition and attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology, 25,* 7–13.

Reissig, C. J., Strain, E. C., & Griffiths, R. R. (2009). Caffeinated energy drinks—A growing problem. *Drug and Alcohol Dependence, 99,* 1–10.

Robin, A. L., & Vandermay, S. J. (1996). Validation of a measure for adolescent self-report of attention deficit disorder symptoms. *Journal of Developmental and Behavioral Pediatrics, 17,* 211–215.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide.* Pittsburgh, PA: Psychology Software Tools.

Scholey, A. B., & Kennedy, D. O. (2004). Cognitive and physiological effects of an "energy drink": An evaluation of the whole drink and of glucose, caffeine and herbal flavouring fractions. *Psychopharmacology, 176,* 320–330.

Seidl, R., Peyrl, A., Nicham, R., & Hauser, E. (2000). A taurine and caffeine-containing drink stimulates cognitive performance and well-being. *Amino Acids, 19,* 635–642.

Smith, A. (2002). Effects of caffeine on human behavior. *Food and Chemical Toxicology, 40,* 1243–1255.

Thombs, D. L., O'Mara, R. J., Tsukamoto, M., Rossheim, M. E., Weiler, R. M., Merves, M. L., & Goldberger, B. A. (2010). Event-level analyses of energy drink consumption and alcohol intoxication in bar patrons. *Addictive Behaviors, 35,* 325–330.

Warburton, D. M., & Bersellini, E. (2001). An evaluation of a caffeinated taurine drink on mood, memory, and information processing in healthy volunteers without caffeine abstinence. *Psychopharmacology, 158,* 322–328.

Received July 19, 2010
Revision received September 11, 2010
Accepted October 4, 2010 ■