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Alcohol-induced impairment of balance is antagonized by energy drinks

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Abstract

Background—The acute administration of alcohol reliably impairs balance and motor coordination. While it is common for consumers to ingest alcohol with other stimulant drugs (e.g., caffeine, nicotine), little is known if prototypical alcohol-induced balance impairments are altered by stimulant drugs. The purpose of this study was to examine if the coadministration of a high caffeine energy drink with alcohol can antagonize expected alcohol-induced increases in body sway.

Methods—Sixteen social drinkers (of equal gender) participated in four separate double-blind dose administration sessions that involved consumption of alcohol and energy drinks, alone and in combination. Following dose administration, participants completed automated assessments of balance stability (both eyes open and eyes closed) measured using the Biosway Portable Balance System (Biodex Medical Systems, Inc.). Participants completed several subjective measures including self-reported ratings of sedation, stimulation, fatigue and impairment. Blood pressure and pulse rate were recorded repeatedly.

Results—The acute administration of alcohol increased body sway and the coadministration of energy drinks antagonized this impairment. When participants closed their eyes, alcohol-induced body sway was similar whether or not energy drinks were ingested. While alcohol administration increased ratings of sedation and fatigue, energy drink administration increased ratings of stimulation and reduced ratings of fatigue. Modest increases in systolic and diastolic blood pressure following energy drink administration were also observed.

Conclusions—Visual assessment of balance impairment is frequently used to indicate that an individual has consumed too much alcohol (e.g., as part of police standardized field sobriety testing or by a bartender assessing when someone should no longer be served more alcohol). The current findings suggest that energy drinks can antagonize alcohol-induced increases in body sway, indicating that future work is needed to determine if this observation regarding neuromotor functioning applies to alcohol in combination with all types of stimulant drugs.

Keywords

Alcohol; Energy Drinks; Balance; Motor Control; Blood Pressure

Introduction

The acute administration of alcohol reliably impairs the ability to balance when standing. Laboratory studies indicate that alcohol administration results in dose-dependent increases in body sway (Ando et al., 2008; Nieschalk et al., 1999; Zoethout et al., 2012). Since alcohol-induced increases in body sway contribute to feelings of instability when walking, motor impairments that are experienced after drinking alcohol appear to provide social drinkers with feedback that may contribute to their perceptions of their impairment. For example, the results of a recent field study revealed that subjective intoxication ratings given by bar patrons were better predicted by motor impairment and not by cognitive impairment, after controlling for current BrAC (Celio et al., 2014). In essence, motor impairment (or lack thereof) may indicate intoxication levels. An individual feeling imbalanced while standing or walking may be more likely to self-assess impairment. Also, external assessments of alcohol intoxication heavily emphasize observable motor impairment. The standardized field sobriety test used by police requires an individual to stand on one leg or walk a straight line to detect possible alcohol impairment. A bartender may assess that a patron should no longer be served alcohol after observing the inability to stand up without assistance. Given that we (individually and as a society) rely so heavily on motor impairment to detect intoxication, it is interesting that little is known about the impact of stimulant drugs on prototypical alcohol-induced gross motor impairment. Thus, the purpose of this laboratory study was to determine if coadministration of a high caffeine energy drink can antagonize alcohol-induced impairments of balance using an automated measure of body sway.

There appear to be no published human laboratory studies testing the hypothesis that administration of alcohol mixed with energy drinks (AmED) results in less impairment of body sway compared to alcohol alone. However, there are studies that have investigated the combined effects of alcohol and caffeine (the primary psychoactive stimulant ingredient in energy drinks) on gross motor control in laboratory animals. When alcohol is administered to rats and mice, balance and motor coordination impairments are observed. The accelerod (i.e., accelerating rotarod) is an assessment of motor coordination whereby a rat is placed on a rotating rod which is high enough above the ground that the animal is strongly motivated to run on the rotating rod in order to not fall off. Under alcohol, animals have more difficulty maintaining balance and gross motor coordination, as measured by the duration of time spent on the accelerod. The findings of one study revealed that coadministration of caffeine dose-dependently attenuated the alcohol-induced impairment on the accelerod test in rats (Connole et al., 2004). Studies with mice and rats from different labs have revealed that coadministration of caffeine or energy drinks with alcohol results in greater locomotor activity (an indirect means of detecting less motor impairment) when compared to alcohol alone (Fritz et al., 2016; May et al., 2015; Takahashi et al., 2015). Antagonism of alcohol-induced motor impairment by caffeine may be related to preference for AmED over alcohol. Rats prefer an environment associated with AmED (as measured by conditioned place

preference) as compared to alcohol alone, and those same animals display better motor control following AmED versus alcohol alone (Takahashi et al., 2015). Thus, in humans and animals, poor balance and coordination following the use of a drug may make the experience less rewarding.

Comparing AmED versus alcohol alone on a measure of body sway in humans may provide a possible mechanism explaining why consumption of AmED is associated with altered subjective state. Reviews of this literature (including laboratory studies, field studies, and surveys) reveal that consumption of AmED (compared to alcohol alone) is associated with subjective self-reported ratings of enhanced stimulation, reduced sedation, and/or reduced impairment/intoxication (Marczinski & Fillmore, 2014; Peacock et al., 2014). However, not all reviews conclude that energy drinks or other caffeinated beverages can alter perceived intoxication (Benson et al., 2014). It is possible that the variability in subjective outcomes in the AmED literature may partly reflect whether or not a motor task or motor feedback was part of the study design. Even the opportunity to walk around the lab might affect subjects' subjective ratings. When we have reported subjective state changes for AmED, we have also observed that energy drinks antagonized alcohol-induced impairments on motor speed, as measured by reaction time computer tasks (Marczinski & Fillmore, 2003; Marczinski et al., 2011, 2017).

The above discussion suggests that examining body sway differences for AmED versus alcohol alone is theoretically interesting. This question is also important for public health. Data from one longitudinal study revealed that 40% of college students reported AmED during the past 6 month period and AmED use initiation during the study was associated with increases in alcohol consumption (Mallett et al., 2015). Since AmED consumers are more likely to screen positive for alcohol dependence when compared to alcohol alone consumers (Cheng et al., 2012; Droste et al., 2014; Patrick et al., 2014; Snipes 2015), the high rates of AmED use in adolescents is concerning (Reid et al., 2015). It is a robust and consistent observation in very large samples gathered from a variety of countries around the world, use of AmED (as compared to alcohol alone) is associated with greater risk for binge drinking and other risky behaviors such as driving while impaired (Emond et al., 2014; Martz et al., 2015; Patrick & Maggs, 2014; Reid et al., 2015; Scalese et al., 2017). When examining alcohol alone, heavier drinkers display more tolerance (acute or chronic) to alcohol-induced motor impairment when compared to lighter drinkers (Fillmore & Weafer, 2012; Miller et al., 2012). Thus, gait and balance impairments following drinking may be conferring important feedback that keeps drinking doses moderate and safe. Understanding how mixing stimulants with alcohol alters gait and balance may provide us with clues about why some social drinkers (including AmED consumers) transition to more risky drinking patterns, whereas other social drinkers not develop problems with alcohol.

Therefore, the purpose of this study was to determine if alcohol-induced increases in body sway can be antagonized by energy drinks. Since automated assessments have been developed to assess neuromuscular control, this study utilized the Biosway Portable Balance System to measure body sway. Although this newer technology has not been widely adopted by alcohol researchers, it has been used in other recent published research for other health conditions related to cerebellum functioning (El-Gohary et al., 2016; Fortado et al., 2016;

Nepocatyh et al., 2016; Zesiewicz et al., 2017). For this study, using a within-subjects factorial design, the effects of alcohol and energy drinks, alone and in combination, were assessed using four separate double-blind dose administration sessions. Following dose administration, participants completed automated assessments of balance and self-reported subjective ratings of sedation, stimulation, fatigue, and impairment. Finally blood pressure and pulse rate were also assessed repeatedly during the testing sessions. Based on the findings from the animal literature, we predicted that alcohol-induced impairments of body sway should be antagonized by energy drinks. Based on the findings from the AmED literature, we predicted that self-reported increases in stimulation and reductions in sedation/fatigue would be observed for AmED as compared to alcohol alone. Given that subjective state changes may reflect drug-induced changes in physiological arousal, blood pressure and pulse rate readings were assessed. As such, a comprehensive assessment of both objective and subjective measures occurred following all doses.

Materials and Methods

Participants

Sixteen social drinkers (8 women) between the ages of 21 and 30 participated in this study. Participants were required to be of the legal drinking age (i.e., 21 years) and 30 years was the maximum age to be included in this study. Equal numbers of men and women were intentionally recruited for this study. The self-reported racial makeup of the sample included 2 African American, 1 Asian, and 13 Caucasian participants. For ethnicity, none of the participants identified as being Hispanic. All volunteers completed questionnaires that provided demographic information and physical/mental health status. Exclusion criteria included self-reported psychiatric disorder, diabetes, phenylketonuria, substance abuse disorders, head trauma, or other central nervous system injury. Individuals who reported being very light drinkers (i.e., less than 2 U.S. standard drinks of 14 grams of pure alcohol per month) were excluded. Drinkers with a potential risk of alcohol dependence were also excluded, as determined by a SMAST score (Selzer et al., 1975) of 5 or higher or an AUDIT score (Barbor et al., 1989) of 8 or higher (Barry & Fleming, 1993). Inclusion criteria consisted of self-reported consumption of at least one energy drink in the past year, and consumption of at least one caffeinated beverage in the past 2 weeks (e.g., soft drink, energy drink, coffee, or tea).

For safety reasons, a urine analysis at the start of every session was used to screen out any volunteer who tested positive for recent use of amphetamines, barbiturates, benzodiazepines, cocaine, ecstasy, methamphetamine, opiates, and tetrahydrocannabinol (uVera Diagnostics, Inc., Norfolk, VA). No volunteers tested positive in this study. Likewise, both self-report and urine gonadotrophin (HCG) levels were assessed so that no females participated who were pregnant or breast-feeding. For participant recruitment, flyers were placed on university community bulletin boards and announcements about the study were included in university student e-mail distribution lists. Interested volunteers called the lab to find out more information about the study. All volunteers provided informed consent before participating. The Northern Kentucky University Institutional Review Board approved this study. Participants who completed the entire five session study (which included one baseline and

four dose administration sessions) received \$130 in compensation. Data collection for this study occurred in 2015.

Apparatus and Materials

Personal Drinking Habits Questionnaire—The Personal Drinking Habits Questionnaire (PDHQ: Vogel-Sprott, 1992) measures an individual's recent typical drinking habits including number of standard drinks (i.e., bottles of beer, glasses of wine, and shots of liquor) typically consumed during a single drinking episode, dose (grams of absolute alcohol per kilogram of body weight typically consumed during a single drinking episode), weekly frequency of drinking, and hourly duration of a typical drinking episode. The PDHQ also measures history of alcohol use in the number of months that an individual has been drinking on a regular basis or on social occasions.

Timeline Follow-Back—The Timeline Follow-Back (TLFB: Sobell & Sobell, 1992) assesses self-reported daily patterns of alcohol consumption during the past 30 days including maximum number of continuous days of drinking, maximum number of continuous days of abstinence, total number of drinking days, total number of drinks consumed in the past month, highest number of drinks consumed in one day, total number of heavy drinking (5+ drinks) days, and total number of 'drunk' days (i.e., days on which the participant self-reported feeling intoxicated).

Caffeine Use Questionnaire—The Caffeine Use Questionnaire (CUQ) assesses self-reported typical average daily caffeine consumption in milligrams per kilogram of body weight. Estimates of the caffeine content in foods and beverages relied on published sources (Barone & Roberts, 1996; McCusker et al., 2006) and manufacturer websites for newer products.

Impulsivity Measures—Two measures assessed self-reported impulsivity, with higher scores indicating greater impulsivity. The Eysenck Impulsiveness Questionnaire (Eysenck et al., 1985) assesses impulsivity using 19 yes/no questions. The Barrett Impulsiveness Scale-11 (BIS-11; Patton et al., 1995) assesses impulsivity by asking participants to rate how typical 30 different states are from them on a 4-point Likert scale.

Biosway Balance Assessment—The Biosway Portable Balance System (Biodex Medical Systems, Inc., Shirley, NY) was used to assess balance using a standardized testing protocol. For this neuromuscular control testing, the participant stands on the firm surfaced platform and looks at a color touch screen display at eye level. The research assistant always stands beside the subject during testing in case a subject feels imbalanced on the platform. After inputting demographic information including body height, the participant places his or her feet about hip width apart on the platform in a standardized location which is indicated on the platform. The feet are slightly turned out with the big toes at a predetermined 10 degree angle. Arms hang naturally along the side of the body. The participant is instructed to look forward at the screen during all testing and not down at the feet. Two standardized assessments were used for this study: 1) clinical test of sensory integration and balance (CTSIB) with eyes open, and 2) CTSIB with eyes closed.

For the CTSIB tests (eyes open and then eyes closed), the participant is given a three second audible beep countdown before testing begins. For each 30 second trial, the participant is asked to keep as still as possible and keep his or her body centered (i.e., not leaning forward, backward, or to either side). There are three trials with eyes open and three trials with eyes closed. The trials are separated by a 10 second break. The Biosway calculates an overall sway index as the standard deviation of the recorded position away from the center for the three trials for each test (eyes open and then eyes closed). Higher sway index scores indicate greater deviations from the center (i.e., greater variability in postural stability indicating more swaying of the body). The Biosway testing including the proper positioning of the feet and body takes about 5 minutes to complete.

Blood Pressure and Pulse Rate—Resting blood pressure and pulse rate were recorded using a Medline Automatic Blood Pressure Monitor (Medline Industries, Inc., Mundelein, IL). For readings, participants were asked to remove any bulky material from the left arm and rest the arm on the table with the palm facing up.

Biphasic Alcohol Effects Scale—Self-reported subjective ratings of stimulation and sedation were evaluated using the Biphasic Alcohol Effects Scale (BAES: Martin et al., 1993). This 14-adjective rating scale includes seven adjectives describing stimulation effects (e.g., stimulated, elated) and seven adjectives describing sedation effects (e.g., sedated, sluggish). The participant rates each item on an 11-point Likert scale ranging from 0 (not at all) to 10 (extremely). The sedation and stimulation scores are summed separately (subscale score range of 0 to 70).

Subjective Effect Ratings—A two-item 100 mm visual analogue scale was used to assess the self-reported fatigue and impairment. The participant indicates rates each item by marking a point along the line which has end anchors of not at all (0 mm) and very much (100 mm). In addition, participants completed a beverage rating scale to report their perceived alcoholic content of the beverages in terms of bottles of beer containing 5% alcohol. The scale ranged from 0 to 10 bottles of beer, in 0.5 bottle increments (Fillmore & Vogel-Sprott, 2000). Finally, a willingness to pay scale was used to assess how much the participant thought the administered beverage was worth if it were sold in a bar. The scale ranged from 0 to \$10, in 50 cent increments.

Procedure

Prelaboratory Screening—Potential volunteers were informed during a phone screening that the purpose of this five-session study was to study the effects of alcohol and energy drinks on behavior. Individuals were notified that the study procedures included participation in one baseline session followed by four separate dose administration sessions that involved consumption of alcoholic, soft drink, and/or energy drink beverages. Individuals were told that the study procedures included completion of variety of questionnaires and assessments of balance which involved standing on a platform. The contents of beverages were never disclosed to participants but they were informed that the amount of alcohol consumed in a session may be equivalent to approximately four standard beers and the energy drink might contain the amount of caffeine found in a cup of coffee.

Before any test 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.

Baseline Session—Each participant was tested individually by a trained research assistant in the Department of Psychological Science laboratories at Northern Kentucky University. Testing occurred between the hours of 10:00 a.m. and 4:00 p.m. Testing times within one subject were kept as similar as possible and did not vary more than 4 hours from the baseline session start time. Upon arrival in the lab for the first session, the participant was asked to provide informed consent. The participants also completed a general health questionnaire, PDHQ, TLFB, CUQ, Eysenck, and BIS-11 questionnaires. After completing the questionnaires, the participant had their blood pressure and pulse rate assessed before being asked to complete the CTSIB tests (eyes open and then eyes closed) on the Biosway.

Dose Administration Sessions—Sessions two through five were dose administration sessions. At the start of every dose administration session, the participant was weighed and completed a medical screening questionnaire to ensure that the participant was in good general health and had not recently taken any prescribed or over-the-counter medications. A zero breath alcohol concentration (BrAC) was confirmed using an Intoxilyzer Model 400 (CMI Inc., Owensboro, KY). The participant was then asked to provide a urine sample the private bathroom in the lab. The research assistant immediately tested the urine sample for drug metabolites and pregnancy to ensure that no subject was administered alcohol if it was contraindicated.

On each test day, the participant received one of four possible doses: (1) 1.97 ml/kg vodka + 5.91 ml/kg decaffeinated soft drink; (2) 1.97 ml/kg vodka + 5.91 ml/kg energy drink; (3) 5.91 ml/kg decaffeinated soft drink; and (4) 5.91 ml/kg energy drink. Dose administration was double-blind and dose order was counterbalanced between subjects. Doses were calculated based on body weight and the alcohol doses were reduced by 87% for female participants. For the alcohol doses, the 1.97 ml/kg vodka (40% alcohol/volume Smirnoff Red Label vodka, No. 21, Smirnoff Co., Norwalk, CT) was chosen as this does results in a moderate peak BrAC of approximately .06-.07 g% (Marczinski et al., 2017). The alcohol doses were mixed with either Squirt (Dr. Pepper Snapple Group, Plano, TX), a decaffeinated carbonated soft drink or with Red Bull energy drink (Red Bull, Switzerland). The 3:1 ratio of energy drink: vodka or decaffeinated soft drink: vodka is a typical preparation served in bars and restaurants. In the control conditions where the energy drink or decaffeinated soft drink was consumed, 10 ml of vodka was floated on the surface of the beverage to give the drink an alcoholic scent (Marczinski et al., 2017).

Testing Battery—After participants received their assigned beverage a plastic cup and consumed it within 10 minutes as instructed, the testing battery began. The CTSIB Biosway balance assessment was assessed at 45 and 90 min. after drinking began. The subjective measures were assessed at 35 and 85 min. after drinking began. The beverage rating scale and willingness to pay scale were assessed once at 35 min. Blood pressure and pulse rate readings were assessed at 20, 40, 60, and 80 min. after drinking began. Finally, BrACs were measured at 40, 60, 80, and 120 min. after drinking was initiated.

Data Analyses

For the dependent measures obtained, the data were submitted to separate 2 (Alcohol Dose: 1.97 ml/kg vodka v. 0.00 ml/kg) $\times$ 2 (Energy Drink: 5.91 ml/kg energy drink v. 5.91 ml/kg decaffeinated soft drink) within-subject analyses of variance (ANOVAs). Time was included as a within-subjects variable in analyses where the dependent measure was assessed more than one time during a dose session.

Gender was included as an initial between-subjects factor in all analyses. However, no main effects or interactions with gender were obtained for the postadministration testing dependent measures. Therefore, gender is only reported in the analyses for the demographic characteristics and baseline measures related to drinking habits. In addition, gender is reported as a variable in the analysis of BrACs since a dose reduction was included as part of the study protocol with the anticipation that the dose reduction should result in no gender differences in BrACs. SPSS 17.0 was used to conduct all analyses where .05 was set as the alpha level for all statistical tests.

Results

Demographic Characteristics

Table 1 provides all demographic and baseline questionnaires measures for the male and female participants. Possible gender differences for the baseline measures reported in Table 1 were examined using independent samples *t* tests. In this sample, males were significantly older than females, $t(14) = 2.52$, $p = .024$. Males also weighed more than females, $t(14) = 2.92$, $p = .011$. Finally, males self-reported consuming a higher number of drinks in one day on the Timeline Follow-back compared to females, $t(14) = 2.34$, $p = .035$. For the remaining tests, no significant differences were obtained for any of the measures, $ps > .05$.

Breath Alcohol Concentrations

No detectable BrACs were observed under the energy drink or placebo conditions. For only the alcohol conditions, the results of a 2 (Gender) $\times$ 2 (Energy Drink) $\times$ 4 (Time) mixed design ANOVA revealed a main effect of Time, $F(3,12) = 18.06$, $p < .001$, $\eta^2 = .819$. There were no other main effects or interactions for this analysis, $ps > .10$. The mean (*SD*) BrACs at 40, 60, 80, and 120 min. were .065 (.012), .067 (.016), .066 (.012), and .053 (.012) g%, respectively. Pairwise comparisons with a Bonferroni adjustment for multiple comparisons revealed that the mean BrACs recorded at 40, 60, and 80 min. were significantly higher than the 120 min. mean BrAC, $ps < .002$.

Biosway Balance Assessment

The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) $\times$ 2 (Time) within-subjects ANOVA for the CTSIB eyes open test revealed a significant main effect of Alcohol, $F(1,15) = 23.65$, $p < .001$, $\eta^2 = .612$, and a significant Alcohol $\times$ Energy Drink interaction, $F(1,15) = 5.22$, $p = .037$, $\eta^2 = .258$. There were no other main effects or interactions for this analysis, $ps > .166$. Figure 1 illustrates the Alcohol $\times$ Energy Drink interaction, which revealed that the alcohol-induced increase in degrees of body sway was reduced in the presence of the energy drink mixer. A paired samples *t* test revealed that mean body sway was significantly greater in the

alcohol only condition as compared to placebo, $t(15) = 5.37, p < .001$. Furthermore, mean body sway was significantly reduced in the AmED condition as compared to the alcohol only condition, $t(15) = 2.44, p = .028$.

The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) $\times$ 2 (Time) within-subjects ANOVA for the CTSIB eyes closed test revealed a significant main effect of Alcohol, $F(1,15) = 4.88, p = .043, \eta^2 = .246$. There were no other main effects or interactions for this analysis, $ps > .087$. Figure 2 illustrates the main effect of alcohol of greater mean body sway in the presence of alcohol (with or without the energy drink mixer).

Blood Pressure and Pulse Rates

The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) $\times$ 4 (Time) within-subjects ANOVA for the systolic blood pressure readings revealed a significant main effect of Energy Drink, $F(1,15) = 13.24, p = .002, \eta^2 = .469$, and a significant main effect of Time, $F(3,45) = 10.86, p < .001, \eta^2 = .420$. There were no other main effects or interactions for this analysis, $ps > .102$. The main effect of Energy Drink for mean systolic blood pressure readings reflected higher readings when the energy drink was administered ($M = 122.63$ mmHg, $SE = 2.73$) versus not ($M = 118.02$ mmHg, $SE = 2.73$). The main effect of Time for mean systolic blood pressure readings reflected reduced mean values across time. Mean (SE) systolic blood pressure readings at 20, 40, 60, and 80 min. after dose administration were 123.77 (2.67), 120.72 (2.57), 119.13 (2.50), and 117.69 (2.41) mmHG respectively. Pairwise comparisons revealed that the 20 min. time was significantly higher than all other readings.

The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) $\times$ 4 (Time) within-subjects ANOVA for the diastolic blood pressure readings revealed a significant main effect of Energy Drink, $F(1,15) = 5.91, p = .028, \eta^2 = .283$, and a significant main effect of Time, $F(3,45) = 10.44, p < .001, \eta^2 = .410$. There were no other main effects or interactions for this analysis, $ps > .179$. The main effect of Energy Drink for mean diastolic blood pressure readings reflected higher readings when the energy drink was administered ($M = 73.84$ mmHg, $SE = 2.22$) versus not ($M = 71.24$ mmHg, $SE = 1.91$). The main effect of Time for diastolic systolic blood pressure readings reflected reduced mean values across time. Mean (SE) diastolic readings at 20, 40, 60, and 80 min. after dose administration were 74.47 (2.24), 72.08 (1.90), 72.81 (2.09), and 70.81 (1.92) mmHG respectively. Pairwise comparisons revealed that the 20 min. time was significantly higher than 40 and 80 min. readings.

The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) $\times$ 4 (Time) within-subjects ANOVA for the pulse rate readings revealed a significant main effect of Time, $F(3,45) = 11.22, p < .001, \eta^2 = .428$. There were no other main effects or interactions for this analysis, $ps > .078$. The main effect of Time for pulse rate readings reflected increased pulse rates across time. Mean (SE) pulse rate readings at 20, 40, 60, and 80 min. after dose administration were 69.86 (2.42), 72.75 (2.00), 75.11 (2.33), and 75.70 (2.24) beats per minute respectively. Pairwise comparisons revealed that the 20 min. pulse rate was significantly slower than the 60 and 80 min. readings.

Subjective Ratings

Mean (SD) values for all subjective ratings under all four dose conditions (averaged across time) are reported in Table 2. The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) $\times$ 2 (Time) within-subjects ANOVA for the BAES stimulation ratings revealed a significant main effect of Energy Drink, $F(1,15) = 6.32$, $p = .024$, $\eta^2 = .296$. There were no other main effects or interactions for this analysis, $ps > .088$. The main effect of Energy Drink for stimulation ratings reflected higher ratings when the energy drink was administered ($M = 25.28$, $SE = 3.75$) versus not ($M = 18.95$, $SE = 2.75$). The same analysis applied to BAES sedation ratings revealed a significant main effect of Alcohol, $F(1,15) = 30.57$, $p < .001$, $\eta^2 = .671$. There were no other main effects or interactions for this analysis, $ps > .107$. The main effect of Alcohol for sedation ratings reflected higher ratings when alcohol was administered ($M = 15.23$, $SE = 2.39$) versus not ($M = 6.47$, $SE = 1.60$).

The results of a $2 \times 2 \times 2$ ANOVA for ratings of impairment revealed a significant main effect of Alcohol, $F(1,15) = 67.53$, $p < .001$, $\eta^2 = .818$. There were no other main effects or interactions for this analysis, $ps > .052$. The main effect of Alcohol for impairment ratings reflected higher ratings when alcohol was administered ($M = 48.44$, $SE = 5.65$) versus not ($M = 2.81$, $SE = 1.30$). The same analysis applied to ratings of fatigue revealed a significant main effect of Alcohol, $F(1,15) = 17.06$, $p = .001$, $\eta^2 = .532$, and a significant main effect of Energy Drink, $F(1,15) = 6.39$, $p = .023$, $\eta^2 = .299$. There were no other main effects or interactions for this analysis, $ps > .284$. The main effect of Alcohol for fatigue ratings reflected higher ratings when alcohol was administered ($M = 33.31$, $SE = 4.58$) versus not ($M = 14.06$, $SE = 3.06$). The main effect of Energy Drink for fatigue ratings reflected lower fatigue ratings when the energy drink was administered ($M = 18.05$, $SE = 3.52$) versus the decaffeinated soft drink ($M = 29.33$, $SE = 4.13$).

The results of a 2 (Alcohol) $\times$ 2 (Energy Drink) ANOVA for the beverage rating revealed a significant main effect of Alcohol, $F(1,15) = 94.65$, $p < .001$, $\eta^2 = .863$. There were no other main effects or interactions for this analysis, $ps > .646$. The main effect of Alcohol for beverage ratings reflected that participants thought they had consumed more alcohol when alcohol was administered ($M = 3.23$, $SE = 0.29$) versus not ($M = 0.22$, $SE = 0.09$). The same analysis for the willingness to pay ratings revealed a significant main effect of Alcohol, $F(1,15) = 31.64$, $p < .001$, $\eta^2 = .678$, and a significant main effect of Energy Drink, $F(1,15) = 4.57$, $p = .049$, $\eta^2 = .234$. There was no interaction, $p = .827$. The main effect of Alcohol for pay ratings reflected that participants would pay more for the drink they received when alcohol was administered ($M = \$3.72$, $SE = 0.42$) versus not ($M = \$1.61$, $SE = 0.18$). The main effect of Energy Drink for pay ratings reflected that participants would pay more for the drink they received when the energy drink was administered ($M = \$2.88$, $SE = 0.28$) versus the decaffeinated soft drink ($M = \$2.45$, $SE = 0.28$).

Discussion

The results of the current study demonstrated that the acute administration of alcohol resulted in increased body sway. When participants had their eyes open, alcohol induced increases in body sway were reduced in the presence of the energy drink mixer. By contrast, antagonism of alcohol-induced body sway by the energy drink mixer was not observed when

participants closed their eyes, indicating that visual feedback plays a role in energy drink antagonism of alcohol-induced motor impairment. In addition, energy drink administration resulted in increases in both systolic and diastolic blood pressure, although these changes were relatively small in magnitude. Prototypical subjective effect ratings were observed in this study, as alcohol administration increased ratings of sedation, fatigue, and impairment. In addition, energy drink administration increased ratings of stimulation and decreased ratings of fatigue. Finally, participants stated that they would be willing to pay more money for alcoholic beverages and energy drink beverages.

The above described findings are consistent with animal studies where the acute administration of alcohol impairs gross motor control and caffeine (the primary psychoactive ingredient in energy drinks) antagonizes this impairment in a dose-dependent manner (Connole et al., 2004). Consistency with the animal literature suggests that greater evaluation of alcohol-induced impairments of gross motor control in the presence of other stimulant drugs (e.g., nicotine, cocaine, amphetamines) should be investigated by both human and animal researchers to determine if this is an important factor in developing dependence on alcohol. The rates of smoking in individuals seeking treatment for alcohol dependence are more than twice the rates for individuals matched on a variety of demographic characteristics (for a review, see Guydish et al., 2016). Since it is known in the AmED literature that social drinkers have greater desire to use AmED over alcohol alone (Marczinski et al., 2013, 2016), it could be that poor balance and coordination following the use of any drug makes the experience of the drug less rewarding. Stimulants may increase the reward from alcohol by mitigating motor impairments induced by alcohol administration. The relationship between the rewarding aspects of drugs and gross motor control warrants further exploration. Moreover, it remains unknown if drinkers are aware of this outcome and expect it. The currently available alcohol mixed with energy drink expectancies scales (Linden-Carmichael et al., 2015; MacKillop et al., 2012; Miller et al., 2017) could be revisited to determine if more questions related to gross motor control should be included on these measures.

The design of this study included a variety of objective and subjective measures. The results indicated that enhanced perceptions of stimulation following energy drink administration (alone or with alcohol) coincided with observations of modest increases in systolic and diastolic blood pressure. Thus, perceptions in subjective state may be reflecting underlying physiological arousal. Further, the results from the willingness to pay measure indicate that participants felt willing to pay more for alcoholic drinks and energy drinks. Since AmED beverages typically cost more for consumers than alcohol alone beverages, this study would suggest that consumers are paying more for these AmED beverages because AmED are considered to be of greater value based on the drug experience itself (since participants were unaware of drink contents). More sophisticated measures of behavioral economic indexes of alcohol demand could be applied to better understand these values perceptions for AmED versus alcohol alone beverages.

A few specific study limitations should be noted. In the current study, the peak BrAC was approximately .07 g% (i.e., below the legal limit for driving in the U.S.). This moderate dose of alcohol was intentionally chosen as we were using new technology and we were uncertain

how unstable participants might feel while standing on the raised Biosway platform. Upon completion of data collection, no concerns emerged about measuring balance (eyes open or eyes closed) using the Biosway and future studies could include a variety of alcohol doses. In addition, future work should incorporate differing doses of energy drinks in combination with alcohol as it remains unknown if complete antagonism of the alcohol-induced impairment of body sway could be observed. Another limitation in this study is that we recruited a sample of social drinkers with relatively homogenous drinking habits. Heavier drinkers may be more tolerant to the alcohol-impairing effects on gross motor control and it would be important to know if the presence of the energy drink mixer with alcohol alters body sway in different kinds of drinkers. Finally, future research is needed to determine if the current results impact the effectiveness of police standardized field sobriety testing in detecting alcohol impairment and whether training should be altered to accommodate these findings.

In conclusion, the findings of this laboratory study indicate that alcohol-induced body sway can be antagonized by energy drinks. The findings of the current study might offer an explanation of why consumers of AmED report altered subjective states and find these beverages more rewarding than alcohol alone. The higher reported rates of binge drinking and impaired driving for AmED consumers may stem from consumers not feeling imbalanced after drinking. The results also suggest that we (individually and as a society) might be overemphasizing balance impairments in detecting alcohol impairment and intoxication. Alcohol is commonly used with a variety of stimulant drugs and at least for high caffeine energy drinks, the stimulant may antagonize alcohol-induced body sway.

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Figure 1.

Mean sway index (degrees) for all dose conditions when participants were instructed to keep their eyes open. Vertical bars indicate the standard error of the mean. * indicates a significant difference between the placebo and alcohol alone condition, $p < .001$; # indicates a significance difference between the alcohol and AmED conditions, $p = .028$

Figure 2.
Mean sway index (degrees) for all dose conditions when participants were instructed to keep their eyes closed. Vertical bars indicate the standard error of the mean.

Table 1

Demographic characteristics and self-reported alcohol/caffeine use for the male ($n = 8$) and female ($n = 8$) participants.

	Males		Females	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age	25.88	3.94	22.13	1.46
Weight (kg)	77.98	9.45	64.08	9.61
Body Mass Index	24.04	4.00	23.86	2.51
Daily caffeine use (mg/kg)	2.15	1.50	3.16	2.15
SMAST	0.00	0.00	0.50	1.41
AUDIT	5.38	1.85	4.00	1.77
Eysenck	3.38	3.82	2.13	2.48
BIS-11	49.88	10.72	45.88	7.12
<i>Personal Drinking Habits Questionnaire (PDHQ):</i>				
History (months)	89.88	39.03	50.38	35.10
Frequency (occasions/week)	2.13	2.03	1.34	1.03
Drinks per occasion	3.31	1.75	2.69	1.62
Alcohol dose (g/kg)	0.78	0.37	0.71	0.36
Duration (hour)	3.38	1.62	2.75	2.58
<i>Timeline Follow-back (TLFB):</i>				
Continuous drinking days	2.13	0.99	1.75	0.71
Continuous abstinence days	8.00	3.46	9.38	4.63
Total no. drinking days	7.50	3.07	4.63	2.67
Total no. drinks	24.69	11.91	14.06	10.92
Highest no. drinks in 1 day	6.06	2.24	3.56	2.03
Heavy drinking days	2.00	1.93	0.75	1.75
Drunk days	1.63	1.60	0.75	1.49

Table 2

Mean (SD) self-reported subjective ratings for all four dose conditions for the male ($n = 8$) and female ($n = 8$) participants. For stimulation, sedation, impairment, and fatigue ratings, mean values are averaged from the two time assessments (35 and 85 min. after dose administration).

Variable	Dose Conditions							
	0.00 ml/kg Alcohol				1.97 ml/kg Alcohol (40% abv. vodka)			
	5.91 ml/kg Placebo	SD	M	SD	5.91 ml/kg Energy Drink	SD	M	SD
Stimulation	14.72	13.50	21.00	15.22	23.19	14.88	29.56	19.67
Sedation	8.03	7.57	4.91	6.57	16.84	12.81	13.63	10.03
Impairment	3.00	6.30	2.63	6.65	48.69	25.09	48.19	23.94
Fatigue	19.47	18.63	8.66	12.18	39.19	24.63	27.44	22.32
Beverage Rating	0.16	0.35	0.28	0.68	3.22	1.37	3.25	1.08
Willing to Pay	1.38	0.90	1.84	0.87	3.53	1.67	3.91	1.92