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ORIGINAL ARTICLE

Effect of Red Bull energy drink on cardiovascular and renal function

Frances R. Ragsdale · Tyler D. Gronli · Narjes Batool · Nicole Haight · April Mehaffey · Erin C. McMahon · Thomas W. Nalli · Carla M. Mannello · Crystal J. Sell · Patrick J. McCann · Gary M. Kastello · Tisha Hooks · Ted Wilson

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Abstract Energy drink consumption has been anecdotally linked to the development of adverse cardiovascular effects in consumers, although clinical trials to support this link are lacking. The effects of Red Bull® energy drink on cardiovascular and neurologic functions were examined in college-aged students enrolled at Winona State University. In a double-blind experiment where normal calorie and low calorie Red Bull® were compared to normal and low calorie placebos, no changes in overall cardiovascular function nor blood glucose (mg/dL) were recorded in any participant ($n = 68$) throughout a 2-h test period. However, in the second experiment, nine male and twelve female participants subjected to a cold pressor test (CPT) before and after Red Bull® consumption showed a significant increase in blood sugar levels pre- and post Red Bull® consumption. There was a significant increase in diastolic blood pressure of the male volunteers immediately after submersion of the hand in the 5°C water for the CPT. Under the influence of Red Bull®, the increase in diastolic pressure for the male participants during the CPT was negated. There were no significant changes in the blood pressure of the female participants for the CPT with or without Red Bull®. Finally, the CPT was used to evaluate pain threshold and pain tolerance before and after Red Bull® consumption. Red Bull® consumption was associated with a significant increase in pain tolerance in all participants. These findings suggest that Red Bull® consumption ameliorates changes in blood pressure during stressful experiences and increases the participants' pain tolerance.

Keywords Energy drink · Red Bull · Caffeine · EKG · Pain

F. R. Ragsdale (✉) · T. D. Gronli · N. Batool · N. Haight · A. Mehaffey · E. C. McMahon · T. Wilson
Department of Biology, Winona State University, Winona, MN 55987, USA
e-mail: fragsdale@winona.edu

T. W. Nalli
Department of Chemistry, Winona State University, Winona, MN 55987, USA

C. M. Mannello · C. J. Sell · P. J. McCann · G. M. Kastello
Department of Health, Exercise and Rehabilitative Sciences, Winona State University, Winona, MN 55987, USA

T. Hooks
Department of Mathematics and Statistics, Winona State University, Winona, MN 55987, USA

Introduction

Energy drinks are widely used by college-aged individuals and Red Bull® is among the most popular with annual global sales of several billion dollars (Boyle and Castillo 2006; Malinauskas et al. 2007; Reissig et al. 2008). The company's claim that Red Bull® will "give you wings" suggests that consumption of their product will provide the consumer with more energy and enhanced performance, both mentally and physically. The manufacturers credit these physiologic and neurologic benefits to Red Bull®'s active ingredients that include caffeine (approximately 32 mg/dL), glucuronolactone (approximately 240 mg/dL), and taurine (approximately 400 mg/dL). In contrast to these potential beneficial effects, energy drink consumption has been anecdotally linked to ventricular tachycardia and to symptoms of cardiovascular disease (Clayfield 2008). These potential cardiovascular complications in young consumers were the impetus for Norway and Demark to withhold authorization of the sale of Red Bull® (Norquist

2008; Palmer 2008). Only recently has France authorized the sale of this product (Tandy 2008).

Red Bull® consumption has been demonstrated to enhance mental alertness and performance. Alford et al. (2001) found that Red Bull® improved reaction times, alertness and concentration, mental acuity skills that might be considered important to the college student. However, Bichler et al. (2006) examined the influence of Red Bull® on short-term explicit memory in undergraduate students by focusing on the synergistic effect of caffeine and taurine, and found that consumption of the caffeine–taurine combination did not change the students' performance on memory assessment compared to caffeine alone. Therefore, the overall benefit for enhanced mental prowess is still in question; the reproducibility and significance of both of these studies are questionable given their small study size of 24 and 14, respectively (Alford et al. 2001; Bichler et al. 2006).

In terms of physiology, most of the documented changes have focused on the volunteers' blood pressure and heart rate at rest. Overall, the results are not conclusive for either increased blood pressure or decreased heart rate with the consumption of an energy drink. In a preliminary experiment, Alford et al. (2001) did not observe any significant change in blood pressure or heart rate after consuming Red Bull®. However, an additional experiment found significant changes in heart rate, alertness and athletic endurance after the consumption of Red Bull®. The two experiments were conducted utilizing different caffeine-abstinence regimes. In the preliminary study, participants did not undergo a fasting period for caffeine, while with the second experiment an abstinence period is inferred. These researchers conclude the differences in cardiovascular parameters in their two studies are due to acute caffeine withdrawal (Alford et al. 2001). Robertson et al. (1978) found similar effects due to acute caffeine withdrawal.

Previous investigators have documented non-deleterious effects of Red Bull® consumption on cardiovascular function. Baum and Weiss (2001) utilizing echocardiology determined that administration of a Red Bull®-like beverage (with caffeine and taurine) significantly increased the contractility of the left atrium. This increase in the contractility of the left atrium could account for the higher left end-diastolic volume leading to an increase in stroke volume. Their conclusion was that taurine either alone, or in combination with caffeine, was responsible for the increase in stroke volume (Baum and Weiss 2001). However, these investigators did not observe an expected change in heart rate. Bichler et al. (2006) report a decrease in heart rate 45 min after caffeine and taurine ingestion; however, there was no change in mean arterial pressure over this same time period. These investigators did report an increase in mean arterial pressure after the memory assessment test that led them to speculate that caffeine and taurine in combination with a stressful event may elevate blood pressure and heart rate via a catecholamine release (Bichler et al. 2006). A physical stressor like the cold pressor test was not used.

Caffeine is characterized as a central nervous system stimulant promoting activation of the sympathetic adrenal–medullar system. Furthermore, caffeine is known to elevate blood pressure during stressful psychological situations (Lane 1983; Lane and Williams 1985, 1987; Lane et al. 1990) and physiological stress, such as exercise (Pincomb et al. 1985; Lovallo et al. 1989; Sung et al. 1990). Increases in blood pressure appear to be due to increases in vascular resistance rather than stroke volume given there are minimal changes in heart rate (Whitsett et al. 1984; Sung et al. 1990). However, previous investigators had suggested that the increase in blood pressure was due to increased sympathetic nervous system stimulation (Robertson et al. 1978).

Taurine, on the other hand, seems to suppress sympathetic nervous system stimulation by modulating cyclic nucleotide content in heart cells (Mal'Chikova et al. 1979; Mal'Chikova and Elizarova 1981). Taurine also appears to influence cardiac muscle by mobilizing Ca^{++} stores primarily in reperfusion of ischemic hearts (Huxtable and Bressler 1973; Pasantes-Morales et al. 1982; Öz et al. 1999). If this calcium mobilization occurs with taurine distinct from ischemia, this may account for the increased stroke volume after Red Bull® consumption as noted in Baum and Weiss (2001).

Previous studies of the effects of Red Bull® have been limited by the small number of subjects. This study consisted of two experiments on the physiological effects of Red Bull® energy drink in college-aged students. The purpose of the first experiment was to determine if consumption of Red Bull® was associated with any cardiovascular alterations as measured by ECG, blood pressure and heart rate, or in blood glucose and renal physiology (i.e., urine specific gravity and urine formation rate). The second experiment was designed to address the addition of a physical stressor to the physiological effects of Red Bull® consumption in college-aged students. Specifically, the second experiment measured heart rate, blood pressure, and pain perception before and immediately after the cold pressor test.

Materials and methods

This study was performed following approval by the Winona State University Institutional Review Board and subject informed consent was obtained prior to participation.

Subjects

Sixty-eight undergraduates (48 females and 21 males, average age = 19.8 ± 1.6 years) from the Human Anatomy and Physiology course at Winona State University volunteered for the first exercise examining the effects of Red Bull® consumption on blood glucose, salivary caffeine, cardiovascular, and renal physiology. Twenty-one upper division students (12 female and 9 males, average age = 22) were recruited for the second exercise examining the effects of Red Bull® on pain perception and blood pressure when exposed to a physical stressor. All volunteers were self-described as health, with no history of cardiovascular, urinary, digestive or metabolic diseases including but not limited to noninsulin dependent diabetes. All subjects were familiar with Red Bull® and many of the participants had previously consumed this beverage under recreational circumstances, although all agreed not to consume Red Bull® for a minimum of 24 h prior to taking part in these studies. All subjects were instructed to fast for 12 h prior to the onset of the experiment and were told to abstain from caffeine and nicotine specifically throughout this time frame, although water was permitted.

Study design and procedures

The first study was a double-blind exercise where the volunteers were assigned to one of four treatments upon arrival at the laboratory. These treatments were Normal Calorie Red Bull® (250 mL can, 110 cal), Low Calorie Red Bull® (250 mL, 10 cal), high calorie placebo (250 mL, 110 cal) and low calorie placebo (250 mL, 10 cal). The placebos were prepared with carbonated water, tap water, and dextrose. Banana flavor (FLAVORx®, Columbia, MD, USA) and green food coloring were added to all beverages to try and mask the flavor of the Red Bull® and placebo treatments. Upon completion of the exercise, 38 of the 68 participants were unable to correctly identify their assigned beverage. This study assessed heart rate, blood pressure (systolic and diastolic pressures), ECG's, blood glucose levels, urine specific gravity, urine formation rates, and saliva caffeine concentrations. The sampling intervals were at 0, 60 and 120 min Red Bull® consumption. Heart rates and ECG's were collected on a PowerLab (ADInstruments, Colorado Springs, CO, USA) for 30 sec recordings at each of these intervals. Electrocardiographic analysis consisted of atrial and ventricular ectopy count, QTI: Q–T interval, QTI_{rc}: rate-corrected QT interval, SDNN: heart rate variation expressed as standard deviation of the R–R interal, pNN50: count of consecutive normals sinus rhythm that exceed 50 milliseconds (ms), pNN50%: percentage of all counted R–R intervals with successive normal sinus R–R intervals >50 ms, QRS: QRS duration expressed in ms, ST: change in the ST-segment relative to the isoelectric line, T-wave: count of T-wave inversions. Blood pressures were measured by an automated sphygmomanometer (Omron Healthcare Inc., Banncockburn, IL, USA). Blood glucose measurements were collected using Accu-Chek Blood Analyzers (Roche Diagnostics Inc., Indianapolis, IN, USA). Urine samples were analyzed with Urisys 1100 (Roche Diagnostic Inc., Indianapolis, IN, USA) for specific gravity and pH. In addition, urine volumes were recorded for the 60 and 120 min samples and urine formation rates were calculated. Saliva samples were collected in microcentrifuge tubes and frozen at −70°C until solid-phase extraction (Bondesil, $CHCl_3$, proxyphylline internal standard) and GC_MS analysis on a HP-5MS (30 m × 0.25 mm × 0.25 μm) column. Selected-ion chromatograms (m/z = 194) were integrated and peak areas corrected based on response factors generated from standard solutions. Statistical comparisons were made using SAS PROC MIXED to carry out a repeated measures analysis (SAS Institute Inc., Cary, NC, USA).

The second study assessed blood pressure, heart rate, pain threshold, pain tolerance, and overall pain assessment (VAS) before and directly after a cold pressor test pre- and postprandial Red Bull® consumption. The cold pressor test by its very nature as a stress test has been shown to increase MAP (Reiser and Ferris 1947; Lafleche et al. 1998; Bichler et al. 2006). Initial blood pressure and heart rate measures were repeatedly taken until three consistent readings were obtained (approximately 20 min). With the cold pressor test, subjects were asked to submerge their non-dominant hand into a 5°C bath upon the "start" signal. The test duration was limited to 5 min to restrict tissue damage due to cold exposure. Pain threshold (sec) was defined as the elapsed time, the hand was in the cold water bath (5°C) until the volunteer perceived pain. The pain tolerance (sec) was determined when the volunteer could no longer keep their hand in the cold water or completion of the 5-min time limit. A pulse pressure monitor on a finger of their dominant hand recorded heart rate throughout the duration of the exercise. Consumption of Red Bull® was 40 min after completion of the first cold pressor test. Statistical analyses utilized a two-way ANOVA with gender and Red Bull® consumption as factors (SAS Institute Inc., Cary, NC, USA).

Results

In the first study, Red Bull® consumption was associated with a significant increase in saliva caffeine concentration 60 min post-prandially and salivary caffeine remained elevated beyond the 120 min sample (Table 1). In contrast, salivary caffeine remained unchanged in the two isocaloric

Table 1 Red Bull® energy drink consumption significantly increased the caffeine content of saliva, but did not significantly alter plasma glucose, urine formation rate or urine specific gravity during the 120 min postprandial study period

Treatment-time (min)	Saliva caffeine (μg/ml)	Glucose (mg/dl)	Urine formation rate (ml/min)	Urine specific gravity
NCP-0	2.04 ± 1.53	87.2 ± 11.1	NA	1.020 ± 0.010
NCP-60	3.78 ± 3.39	104.6 ± 26.3	1.58 ± 1.54	1.020 ± 0.010
NCP-120	1.28 ± 1.52	86.7 ± 8.9	2.57 ± 1.45	1.020 ± 0.020
NCRB-0	1.12 ± 1.48	91.7 ± 7.8	NA	1.021 ± 0.005
NCRB-60	11.30 ± 7.40[a]	96.9 ± 19.2	1.75 ± 2.00	1.018 ± 0.007
NCRB-120	12.80 ± 7.10[a]	87.8 ± 7.0	2.60 ± 1.91	1.014 ± 0.007
LCP-0	1.57 ± 1.45	88.9 ± 7.0	NA	1.023 ± 0.010
LCP-60	1.81 ± 1.28	89.6 ± 6.0	1.64 ± 1.78	1.020 ± 0.010
LCP-120	1.55 ± 1.52	87.5 ± 7.4	1.74 ± 1.90	1.020 ± 0.011
LCRB-0	1.27 ± 1.13	88.3 ± 9.6	NA	1.020 ± 0.006
LCRB-60	16.50 ± 11.80[a]	87.8 ± 8.7	1.47 ± 0.91	1.015 ± 0.008
LCRB-120	14.00 ± 10.30[a]	88.9 ± 8.7	2.17 ± 1.5	1.012 + 0.006

NCP normal calorie placebo, *LCP* low calorie placebo, *NCRB* normal calorie Red Bull, *LCRB* low calorie Red Bull

[a] Increased caffeine contents of saliva

Table 2 Red Bull® energy drink consumption resulted in no significant changes in cardiovascular function during the 120 min study period

Treatment and time (min)	Heart rate (beats/min)	Systolic blood pressure (mmHg)	Diastolic blood pressure (mmHg)	Mean arterial blood pressure (mmHg)	Pulse pressure (mmHg)
NCP-0	74.9 ± 9.46	120.4 ± 12.9	76.5 ± 9.2	91.1 ± 9.5	43.9 ± 10.1
NCP-60	72.5 ± 10.9	119.7 ± 14.7	73.6 ± 11.2	88.9 ± 11.9	46.1 ± 7.8
NCP-120	70.4 ± 9.6	117.9 ± 14.3	75.6 ± 11.6	89.6 ± 10.9	42.2 ± 13.4
NCRB-0	75.1 ± 16.2	117 ± 10.9	76.8 ± 8.6	90.2 ± 8.4	40.2 ± 9.2
NCRB-60	72.8 ± 16.0	124.5 ± 10.1	77.9 ± 9.4	93.4 ± 8.5	46.7 ± 9.8
NCRB-120	70.4 ± 12.3	122.7 ± 12.6	76.2 ± 7.8	91.7 ± 7.7	46.5 ± 12.4
LCP-0	76.4 ± 12.0	118.5 ± 10.2	76.4 ± 6.9	90.5 ± 6.9	42.1 ± 9.0
LCP-60	72.0 ± 13.2	120.6 ± 12.3	76.4 ± 7.7	91.2 ± 8.1	44.2 ± 10.3
LCP-120	74.6 ± 12.3	117 ± 10.4	78.1 ± 8.3	91.1 ± 7.9	38.9 ± 9.3
LCRB-0	77.6 ± 13.3	113.8 ± 14.5	73.8 ± 7.7	87.1 ± 9.4	40 ± 9.9
LCRB-60	71.8 ± 13.1	118.4 ± 15.8	76.2 ± 10.7	90.3 ± 11.3	42.2 ± 12.0
LCRB-120	72.4 ± 11.6	120.4 ± 14.2	76.9 ± 8.3	91.4 ± 9.8	43.5 ± 11.1

control groups where caffeine was not ingested. Blood glucose levels fluctuated throughout the experiment in both normal calorie Red Bull® and the isocaloric control, although the increase in blood glucose levels from 0 to 60 min sampling was not significant and were characterized by a large degree of interpersonal variation, there was a significant decrease in blood sugar from 60–120 min interval ($p = 0.02$). Urine formation rate and urine specific gravity were also not changed for the groups examined. Similarly, no significant effects of normal calorie Red Bull®, low calorie Red Bull®, normal calorie control or low calorie control were observed with respect to heart rate, systolic blood pressure, diastolic blood pressure or pulse pressure (Table 2). Several ECG parameters were also observed within the 20 s ECG recordings prepared at 0, 60, and 120 min. Expected increases across time in PNN50%, PNN50, QTI, SDNN, and R–R interval were observed in all groups. QRS duration, ST-segment, T-wave inversion count, and QTI_{rc} did not change from baseline measures in any of the groups. None of the ECG parameters measured demonstrated any difference between groups. The Q–T interval shown in Fig. 1 is one such ECG example. In addition, none of the 20-s ECG records for normal calorie Red Bull®, low calorie Red Bull®, normal calorie placebo or low calorie placebo subjects contained any periods of sinus tachycardia. Furthermore, none of the recordings contains atrial, junctional or ectopic atrial or ventricular depolarizations.

In the second exercise involving the cold pressor test, all subjects demonstrated a significant increase in systolic blood

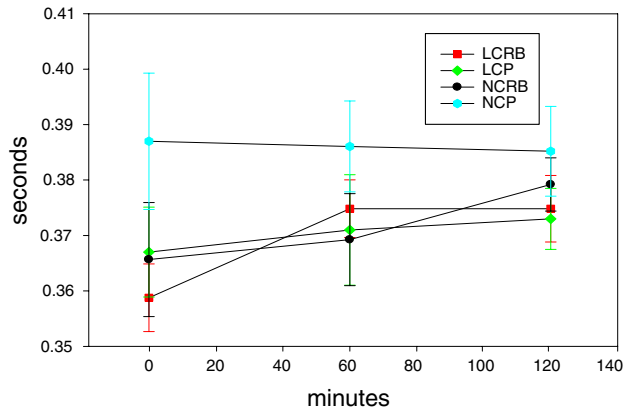

Fig. 1 Red Bull® consumption had no significant effect on QT interval duration (sec) sampled over the three time periods

pressure ($p < 0.001$, $n = 21$) prior to Red Bull® consumption simply due to the activation of the autonomic nervous system via the cold pressor test and this change in systolic pressure was significantly higher in men ($p < 0.001$, $n = 21$) (Fig. 2b). For men their systolic blood pressure rose from 128 to 138 mmHg with the cold exposure, and for women their systolic blood pressure rose from 118 to 123 mm Hg) (Table 3). Finally, there was a significant increase in mean arterial pressure (MAP = diastolic pressure + 1/3 (systolic pressure − diastolic pressure) for all subjects with cold pressor test exposure prior to drinking Red Bull® ($p < 0.001$, $n = 21$) (Table 3; Fig. 2d). Forty minutes after the initial cold pressor test and thirty minutes after the consumption of Red Bull®, all test subjects had elevated MAP. However, there was no additional increase in the blood pressure with the second cold pressor test. The blood pressures for the test subjects were not significantly different from resting values immediately after the second cold pressor test after Red Bull® consumption (Fig. 2).

There was a trend in both males and females after Red Bull® consumption towards a slightly elevated pain threshold, although the overall difference was only marginally significant ($p = 0.075$, $n = 21$) (Table 4). Males are known to have greater pain threshold compared to women (Fillingim and Maixner 1995; Riley et al. 1998; Mitchell et al. 2004), however, the trend for increased pain threshold with Red Bull® consumption was actually larger among the female participants in this experiment. All the women in this exercise perceived pain later in the exercise after Red Bull® consumption (from 32.1 s without RB to 69.5 s with RB) (Table 4). More importantly, the increase in pain tolerance post Red Bull® consumption was significant for all test subjects ($p < 0.001$, $n = 21$) (Table 4). Finally, all participants reported a diminished perception of pain following Red Bull® consumption.

There was a highly significant difference between pre-Red Bull® fasting blood glucose concentrations (90.7 mg/dL ± 2.4, $n = 11$) and post-Red Bull® consumption blood

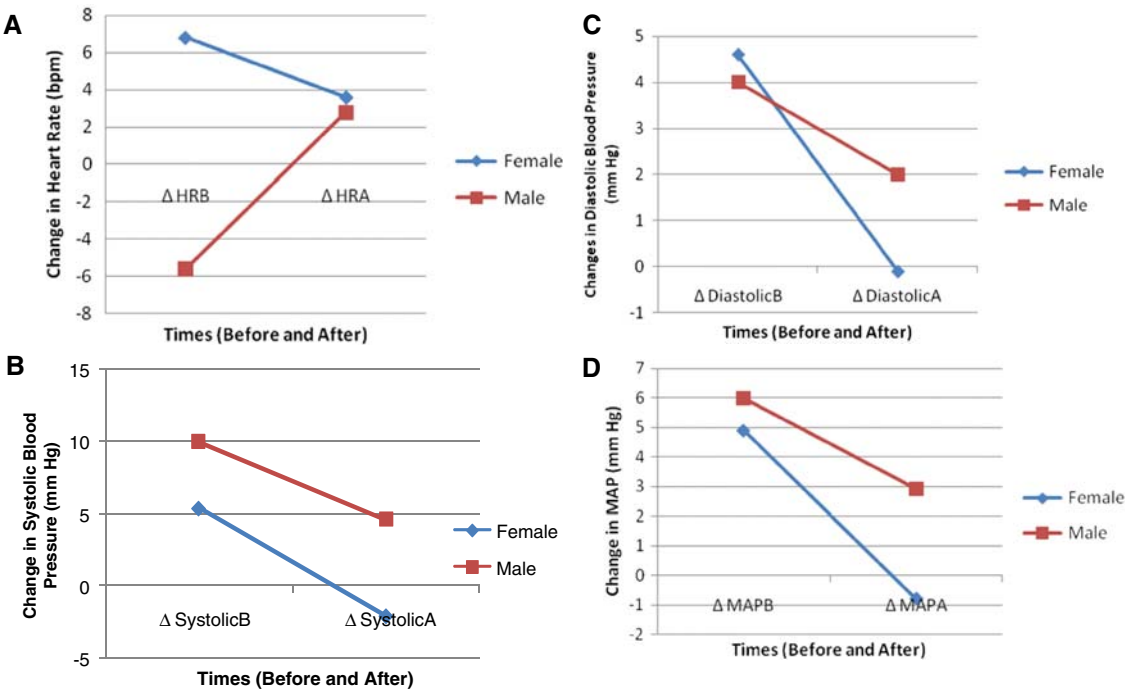

Fig. 2 Comparison of cardiovascular changes in females and males before and after the introduction of a physical stressor (cold pressor test) without and with Red Bull. There was a significant increase in systolic blood pressure in both men and women with the cold pressor test. This attributed to the significant increase in MAP with Cold Pressor test, but this was eliminated with Red Bull

Table 3 Baseline values for subjects prior to cold pressor tests all fall within the normal ranges for males and females after a 12 h fast and prior to testing (average ± standard error)

	Pre-Red Bull® consumption				Post Red Bull® consumption			
	Blood glucose (mg/dL)	Heart rate (BPM)	Blood pressure (mmHg)	MAP (mmHg)	Blood glucose (mg/dL)	Heart rate (BPM)	Blood pressure (mmHg)	MAP (mmHg)
Female	87.1 ± 3.7	82.8 ± 3.8	119.1/75.6	90.1 ± 2.3	122.9 ± 5.5	77.3 ± 3.1	122.9/82.4	95.9 ± 2.4
	$n = 7$	$n = 12$	$n = 12$	$n = 12$	$n = 7$	$n = 12$	$n = 12$	$n = 12$
Male	97.0 ± 4.9	79 ± 4.1	126.3/79	94.8 ± 1.9	135.4 ± 3.6	74.4 ± 3.4	133.6/82.9	99.8 ± 5.4
	$n = 4$	$n = 9$	$n = 9$	$n = 9$	$n = 5$	$n = 9$	$n = 9$	$n = 9$
Average	90.7 ± 2.4	81.1 ± 2.8	122.2/77	90.7 ± 2.2	123.1 ± 4.8	76.1 ± 2.2	127.5/82.6	96.0 ± 1.3
	$n = 11$	$n = 21$	$n = 21$	$n = 21$	$n = 12$	$n = 21$	$n = 21$	$n = 21$

The blood glucose concentration of 11 volunteers was measured after 12 h fast. There was a highly significant increase ($p < 0.001$, $n = 11$) in blood glucose levels after Red Bull® consumption

Table 4 Changes in pain parameters, pre- and post-RedBull consumption

	ΔPain threshold (s)	ΔPain tolerance (s)	ΔVAS (%)
Female	25.1	82.4	−1.3
Male	12.5	44.7	−7.3

The difference in pain tolerance (sec) for the cold pressor test with Red Bull consumption was significant higher ($p = 0.006$, $n = 21$) for both males and females, which indicated that there could be a relationship between the active ingredients of Red Bull and an individual's tolerance for pain

glucose concentrations (123.1 mg/dL ± 4.8, $n = 12$) for both men and women in the second exercise ($p \leq 0.001$, $n = 11$).

Discussion

Consumption of Red Bull® was accompanied by an increase in the saliva caffeine concentration 60 and 120 min post-prandially in the normal calorie Red Bull® group and low calorie Red Bull® group. This elevation in saliva caffeine should reflect a change in the plasma caffeine concentration of the volunteers, although changes in plasma caffeine concentrations were not measured. The increase in saliva caffeine concentration should be similar to that of the consumption of a single strong cup of coffee based on the caffeine load (80 mg) (Shirlow 1983; Kotke and Gehrke 2008). The saliva caffeine concentration remained elevated for the 120 min sampling period again suggesting that the washout time for this drug delivery system is similar to that of coffee. The lack of change in the salivary caffeine in the isocaloric control groups indicated that subjects successfully abstained from caffeine during the 24 h prior to the study.

Surprisingly, there were no changes in the cardiovascular parameters examined following the consumption of Red Bull® in comparison to the effects of the isocaloric placebos. Placebo-controlled studies have previously shown that caffeine increases blood pressure and plasma levels of catecholamine without changes in heart rate (Passmore et al. 1987; Lovallo et al. 1989; Sung et al. 1990). However, there were no significant differences in any cardiovascular parameter examined in the first exercise (Table 1; Fig. 2). Although not significant, there was a slight trend for the heart rate of the Red Bull® treated groups to decrease and the systolic blood pressure to increase compared to the effects of the controls (Table 2). These results are similar to the findings of previous investigations (Alford et al. 2001, Geiss et al. 1994). Caffeine may induce a bradycardia reflex due to vagal stimulation in a laboratory setting (Lane 1983; Whitsett et al. 1984; Lane and Williams 1985, 1987; Pincomb et al. 1985; Lane et al. 1990), although Geiss et al. (1994) suggest that it is the combination of taurine and caffeine that affects the decrease in heart rate. Our blood pressure and heart rate results for the Red Bull® groups and the isocalorie groups were not significantly different for the first experiment suggests that this variability in heart rate was due to increased familiarity with the protocol as the experiment continued rather than due to a caffeine or a caffeine–taurine effect.

Given that caffeine is known to exert a mild diuretic effect, it was expected that normal calorie Red Bull® and low calorie Red Bull® ingestion would be associated with a postprandial decrease in urine specific gravity and an increase in urine formation rate. No such effect was observed. It is probable that following the overnight fast and the early arrival in the laboratory (between 5–6 a.m.), subjects started the study in a slightly dehydrated state. In this condition, the mild diuretic effect of caffeine would be expected to have been negated by the presence of

aldosterone and anti-diuretic hormone, though these hormones were not directly measured in this study.

In regards to the anecdotal Red Bull®-dependent cardiovascular reactions, none were noted in this experiment and a single dose appears to be safe when ingested alone. In the second experiment, exposure to a physical stressor (i.e., CPT) resulted in a significant increase in blood pressure due to activation of the sympathetic nervous system without an increase in blood pressure. Previous investigators have made similar conclusions (Hines and Brown 1932; Greene et al. 1965; Lafleche et al. 1998; Mitchell et al. 2004). There was a significant increase in diastolic and systolic blood pressure in college students prior to Red Bull® consumption ($p = 0.0159$, $n = 21$) assumed to be due to the activation of the autonomic nervous system via the cold pressor test, and this change in blood pressure was significantly higher in males ($p = 0.0226$, $n = 9$) compared to their female cohorts. However, this investigation did not measure plasma catecholamines or skin conduction to document this effect. The increase in blood pressure corresponded to a significant increase in mean arterial pressure (MAP) for all subjects with the CPT exposure prior to Red Bull® consumption ($p = 0.0163$, $n = 21$). The cold pressor test by its very nature as a stressor has been shown to significantly affect mean arterial pressure [MAP = diastolic pressure + 1/3 (systolic pressure − diastolic pressure)] (Bichler et al. 2006; Lafleche et al. 1998; Reiser and Ferris 1947). There was a potential trend for resting blood pressure to be slightly elevated after the consumption of Red Bull® ($p = 0.067$, $n = 21$), but there was no additional increase in blood pressure after the second cold pressor test. The amelioration of the increase in MAP with the consumption of Red Bull® could be attributed to the taurine in the beverage, with its known influence on electrical and mechanical actions of calcium ion pools in heart (Satoh 1998) (Table 2; Fig. 2d).

There was an increase in pain tolerance that could be contributed to Red Bull® consumption. However, this change in pain tolerance may also be attributed to relaxation throughout the trials, or distraction of the volunteers by the evaluator. A significant increase in pain threshold and tolerance was observed in children when sucrose ingestion accompanied the cold pressor test (Pepino and Mennella 2005). The ingestion of sugar in the normal Red Bull® (110 calories) may have contributed to this suppression of pain, although college-aged students should not be considered children and this sugar-effect is absent in adults. That blood pressure remained elevated after the consumption of Red Bull®, but did not change with the cold pressor test may also be attributed to the dampened pain tolerance. Maixner et al. (1982) reported increased pain tolerance in hypertensive rats via a vagal afferent system mechanism.

Geiss et al. (1994) focused on the stimulating effects of Red Bull® in athletic performance after consuming 500 mL (approximately 2 cans) of Red Bull®. Lower catecholamine concentrations and heart rate were observed during maximal performance in athletes who had consumed Red Bull® and these changes led to increased endurance in the athletes (Geiss et al. 1994). Our findings with enhanced pain tolerance following Red Bull® consumption suggest that a component of this enhanced athletic performance may be due to a higher degree of pain tolerance. However, our findings cannot be directly compared because the study by Geiss et al. (1994) had the athletes consume double the amount of Red Bull®.

Red Bull® is a proprietary mix of many ingredients including water, sugars, vitamins and minerals in addition to caffeine and taurine. As a marketing tool, a can of Red Bull® contains a series of vaguely worded statements that indicate that its ingestion is associated with improved performance, endurance, concentration, and metabolic stimulation. This energy drink appears to provide the consumer with a blood sugar increase that may stimulate an insulin response and enhance the glucose pool in body cells. A similar increase in blood sugar concentrations was not present in the low calorie version of the energy drink. Red Bull® also appears to dampen an individual's pain response and this may allow athletes to work out harder and longer thereby leading to enhanced performance. That Red Bull® appeared to negate any additional increase in blood pressure normally associated with a physical stressor also supports this notion of enhanced performance. The present study demonstrated that the consumption of a single can of Red Bull® was not associated with adverse cardiovascular effects. However, larger clinical trials are needed to support the neurogenic claims. Consumption of a can of Red Bull® by college-aged students was not associated with cardiovascular abnormalities. In this respect, consumption of a single can (250 mL) of Red Bull® appears to be safe.

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