



The Influence of Energy Drinks on Lower Limb Neuromuscular Timing and Postural Sway in Healthy Young Adults

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Abstract

Energy drinks have become popular during the last few years. Many researchers explain the benefits the beverage has on sports or college settings. Other studies focused on the negative position of these drinks, such as reducing blood flow and balance alterations. Various modifications related to energy drink intake might be at a more system and physiological level, like the central nervous system and neuromuscular control.

Purpose: This study aims to ascertain the influence of a standard 16-ounce energy drink on neuromuscular timing and standing postural compensation of young, healthy adults while performing a series of complex dual-motor tasks.

Methods: Nine females and four males were recruited, screened, and signed the informed consent to be studied for this work. All participants were apparently healthy young adults with no underlying conditions that could potentially impact muscle activation and balance. The Tibialis anterior and Gastrocnemius neuromuscular timing data were collected with surface EMG electrodes. Accelerometers and gyroscopes were used to collect postural sway data. Subjects were asked to execute four balance tasks pre-energy drink consumption, and the same tasks were repeated post energy drink consumption to equate data points.

Results: Postural Sway was comparable before and after energy drink intake. Neuromuscular timing data indicates modifications of nerve conduction on the Tibialis anterior and Gastrocnemius musculature.

Conclusion: We infer that the ingredients in energy drinks, including guarana and B-vitamins, are altering nerve conduction velocity in postural muscles. Future studies should research the influence of energy drinks in different scenarios and different populations.

Introduction

Energy drinks (Edrinks), beverages that lay claim to increase physical energy levels and improve mental alertness, continue to unceasingly rise in popularity. There are dozens of different brands of energy drinks, with each brand claiming to contribute something new or better to consumers that is unobtainable from competing brands. Every energy drink brand contains a distinct proportion of similar vitamins, minerals, and amino acids, all of which are considered the most popular "dietary supplement" consumed by American youth [1]. Caffeine is the central ingredient in these beverages, with levels

varying between brands ranging from 6 mg to 300 mg per serving, and many containers that may appear to consumers as a single serving often contain 2-2.5 servings [1].

These beverages are frequently consumed by young athletes and students, with a reported 80% of college athletes drinking them to enhance their performance levels [2]. As energy drink companies continue to aim their advertising to young, active populations, the prediction from the global energy drink market is that revenue from these beverages will reach \$61 billion by 2021 [3]. With rising sales and consumption rates in the US, it should be considered vital, if not critical, to discuss the potential risks energy drinks pose to overall health and wellbeing.

As students and employees, individuals are continuously seeking that extra thrust to retain the same level of performance during daily tasks and keep up with societal norms and expectations [4]. With this, it should be noted that energy drinks provide many benefits to individuals, regardless of the brand. Generally, the primary purpose of the intake of energy drinks is for increasing energy, though Heckman and colleagues have found that energy drinks may also improve mood, enhance physical endurance, reduce mental fatigue, and increase reaction time. For a variety of reasons, many individuals consume energy drinks throughout the day, with some having made these beverages a part of their daily routine, needing its specific nutritional contents that are unique to energy drinks to be able to function at their maximum potential, as outlined below.

Caffeine: The principal ingredient found in energy drinks is caffeine. When consumed in moderation (300-400 mg/day), caffeine has been shown to pose several benefits for adults, including the ability to enhance mood, alertness, exercise performance, the speed at which information is processed, awareness, attention, and reaction time [5].

Furthermore, caffeine has the ability to reduce the negative effects related to sleep deprivation and thermogenesis, while also being associated with both reducing food intake and promoting lipolysis [6].

Taurine: As an amino acid found in most energy drinks, the occurrence of taurine in these beverages is as prevalent as that of caffeine [5]. Taurine improves endurance performance and aids in the reduction of the lactic acid build-up that occurs after exercise.

Guarana: Caffeine is a central ingredient in energy drink beverages,

with a common source being from guarana, a plant whose seeds contain approximately four times the caffeine found in coffee beans [7]. Correspondingly, studies have shown that guarana can improve cognitive performance, mental fatigue, and mood at relevant dosages, as well as induce lipid metabolism [5].

B-Vitamins: The augmented concentration of B-vitamins in energy drinks can potentially increase mental alertness, focus, and improved mood [6].

Ginkgo Biloba: Higgins et al. [6] report that this ingredient is believed to be an antioxidant aimed at helping with vasomotor function, memory retention, concentration, circulation, and reducing depression.

L-Carnitine: This amino acid has shown to help with energy levels and increase lipid metabolism via increasing oxygen consumption, inducing hematopoiesis, and limiting platelet aggregation [6].

Creatine: Yunusa and colleagues [5] report creatine helps supply energy to muscles, and L-theanine has shown to steady the brain to enhance concentration.

Nevertheless, consumption of energy drinks (Edrinks) is further exposed to have detrimental effects on the body. These risks are significant to consider, especially for those individuals who consume them on a regular basis. A few of these risks include adverse effects on the flow-mediated dilation (FMD) of arteries, abnormalities in platelet aggregation, endothelial dysfunction, short term increased blood pressure and heart rate, arrhythmias, and changes in well-being, sleep, and mental status [8, 9]. Several studies have observed these changes to the body with a slight distinction to specific ingredients, as those who consume Edrinks or excessive caffeine have shown increased daytime sleepiness and exacerbated symptoms already caused by mental illness [10].

Prior research has thoroughly investigated the effects of Edrinks on the cardiovascular system, energy, wellbeing, and more, as there is evidence that the cardiovascular system is affected and adverse effects on sleep and a sense of well-being occur as a result of regularly consuming Edrinks [9, 10]. However, with the increasing popularity of Edrink usage among youth, inquiries targeting long-term effects, as well as identifying the effects of specific ingredients on the balance motor control system, are yet to be explored. In their study Rosario and Colleagues et al. [11], highlighted the increase in postural sway after the intake of one monster energy drink when compared to a regular caffeine group in apparently healthy young adults. However, the study above focuses on a simple balance task as well as weight distribution.

The intention of the current study at hand is to determine the impact of energy drinks on balance while individually evaluating each of the

systems that comprise it. We will also assess the association between caffeine in Monster energy drinks to posture and muscle activation of the legs during both stable and multitasking activities. These multitasking activities will consist of various motor tasks, such as standing on an unstable surface with eyes open and closed, which will challenge each of the balance systems. During these observations, we expect to describe the impact of Monster energy drinks on postural sway, balance, and muscle activation in healthy young adults while performing various tasks in a static standing position.

Considering impaired balance is one of the most common problems treated by physical therapists [12] and due to both the benefits and detrimental interplay found in existing literature related to energy drinks, the hypotheses for this study are, following the consumption of the energy drink, participants will 1) exhibit an increase in postural instability linked to an increase task complexity, and 2) demonstrate timing alterations in the muscular activation of the tibialis anterior and gastrocnemius during different balance tasks. This study will provide valuable information addressing the improvement of health and wellbeing of youth and possible prevention of future related illnesses.

Study Design

This is a quasi-experimental study investigating the difference in postural sway and muscle activation in healthy young adults following the consumption of a Monster energy drink in comparison and before consuming the energy drink.

Methods

Participants: Recruitment of participants was by word of mouth via research assistants, through social media, and with flyers posted throughout the Texas Woman's University Dallas campus. Males and females between the ages of 21-40 years old (young adults) were recruited for this study. Potential participants were screened for eligibility through the study's predetermined inclusion and exclusion criteria.

In this study, thirteen subjects signed the informed consent and participated in this research, of which, four were male and nine were female, with a mean age of 24.4 ± 1.2 years and a BMI of 23.8 ± 5.7 (Table 1). Each subject signed a consent form before being screened to consuming a standard 16-ounce Monster energy drink within 10 minutes. Participants had stable vital signs, including blood pressure ($116.4 \pm 11.1 / 73.8 \pm 10.1$ mmHg), heart rate (73.2 ± 14.8 bpm), and pulse oximetry (98.5 ± 0.5 %), indicating good cardiovascular health (Table 1). All participants are considered healthy, with no underlying injury or pathology, according to the criteria outlined below.

Characteristics of participants			
Characteristics	Study Participants (n=13)		
Age	m= 24.4± 1.2		
Male	n= 4		
Female	n= 9		
Height	m= 66.1 inches		
Weight	m=148.4 pounds		
BMI	m= 23.8± 5.7		
Cardiovascular Data			
	Pre Edrink	Post Edrink	P value
Systolic (mmHg)	116.4±11.1	119.2±14.5	0.46
Diastolic (mmHg)	73.8±10.1	81.0±8.0	0.11

Table. 1 to be Cont.....

Heart Rate (beats per minute)	73.2±14.8	81.3±17.1	0.05
Oxygen Saturation (%)	98.5±0.5	97.8±2.1	0.26
Foot Heart Rate	N/A	71.5 ± 3.2	
Foot Oxygen Saturation		98.6±1.7	
Time for Cardio Change (minutes)	9.8±3.1		

Table 1: Characteristics of the study participants and cardiovascular Data. Results of paired sample t-tests performed between pre energy drink and post energy drink cardiovascular data. Significance level set at $p \leq 0.05$.

Study Criteria

Inclusion criteria: For this work, we recruited participants of both genders between the ages of 21-40 years old. This study selected this particular age range for two reasons. One, age-related factors that might modify gait and posture are a nonissue for young adults. Also, according to Malinauskas et al. [13], energy drinks are a common practice among this age range population.

Exclusion criteria: This study's goal was to identify alterations in posture and neuromuscular activation; thus, a healthy control population was required. For that intent, we designed the following exclusion criteria:

1. Severe balance problems, evaluated using the Romberg Test if the subject is not able to maintain the position for 30 seconds, it will indicate a positive test for proprioceptive or vestibular deficiencies, and will, therefore, be excluded from the study.
2. Untreated severe visual acuity was evaluated by the Visual Test. The inability to read the label on a vitamin/medication bottle with prescription glasses, if needed, were excluded from the study.
3. BMI > 40, which will be evaluated through the formula, weight (lb) / [height (in)]² x 703. The subject's BMI was compared with the BMI classification table. Subjects that show a BMI of 40 are classified as morbidly obese, which may induce balance disturbances, thus excluding them from the study.
4. Individuals with hypertension, defined by the American Heart Association as an SBP ranging between 130-139 mmHg, and/or DBP ranging between 80-89 mmHg.
5. Back or lower extremity lesion or surgery during the last 6 months, screened through interviews prior participating in this project. These injuries could interpose with the subject performance to complete the different test.
6. The use of drugs that cause drowsiness 24 hours previous to intervention screened through the interview. Drowsiness could interfere with the subject's attention level required to complete the different tests and alter balance.
7. Women that are pregnant or think they might be pregnant, screened through a subjective participant interview. Pregnancy implies postural changes in response to the change in position of the center of mass.

Research Procedures

Subjects who were eligible to participate and agree to partake in this study were instructed to avoid the ingestion of stimulants, including caffeine and/or energy drinks, for a minimum of 24 hours prior to the date of data collection. Following this, participants had EMG surface electrodes placed on the Tibialis anterior and Gastrocnemius muscles of their dominant leg, as shown in Figure 1. The dominant side was determined by asking the participants to answer the following, "when you kick a ball, which foot do you use?" Participants were then fitted with a lumbar three axial accelerometer and gyroscope (Mobility Lab) sensors that capture postural sway (Figure 1). Mean Velocity Anterior-Posterior (AP), Mean Velocity Medial-Lateral (ML), Mean Distance AP, and Mean Distance ML were recorded using APDM's Mobility Lab™ sensors and software.

Pre-Energy Drink Consumption

The subjects' vitals, including SPO₂ and heart rate of both the hands and feet of participants' dominant side, as well as blood pressure, were monitored in the resting, sitting position prior to Edrink consumption. Participants were then asked to perform the balance protocol, consisting of four different balance tasks, 1) eyes open, 2) eyes closed, 3) eyes open with head up and down movement, and 4) eyes closed with head movement, all while standing on a foam mat. The head movements were performed at 60 beats per minute using a metronome, as seen in Figure 1. Participants were instructed to fix their gaze on a designated eye-level point on the wall, located 10 feet away, while constantly moving their head in flexion and extension, consistent with the "yes" motion. Each of the above listed balance tests lasted 15 seconds.

Post-Energy Drink Consumption

Subjects consumed one 16-ounce standard monster energy drink over a time span of 10 minutes. The subjects' vitals, including SpO₂ and heart rate of both the hands and feet of participants' dominant side, as well as blood pressure, were monitored in the resting, sitting position following the beverage consumption to ensure changes in cardiorespiratory data were related to the energy drink. Once the participants' blood pressure changed by at least 5-10mmHg, and heart rate changed by a minimum of 10 bpm, the four balance tasks were then repeated on the foam mat to compare pre-drink consumption and post-drink consumption data.

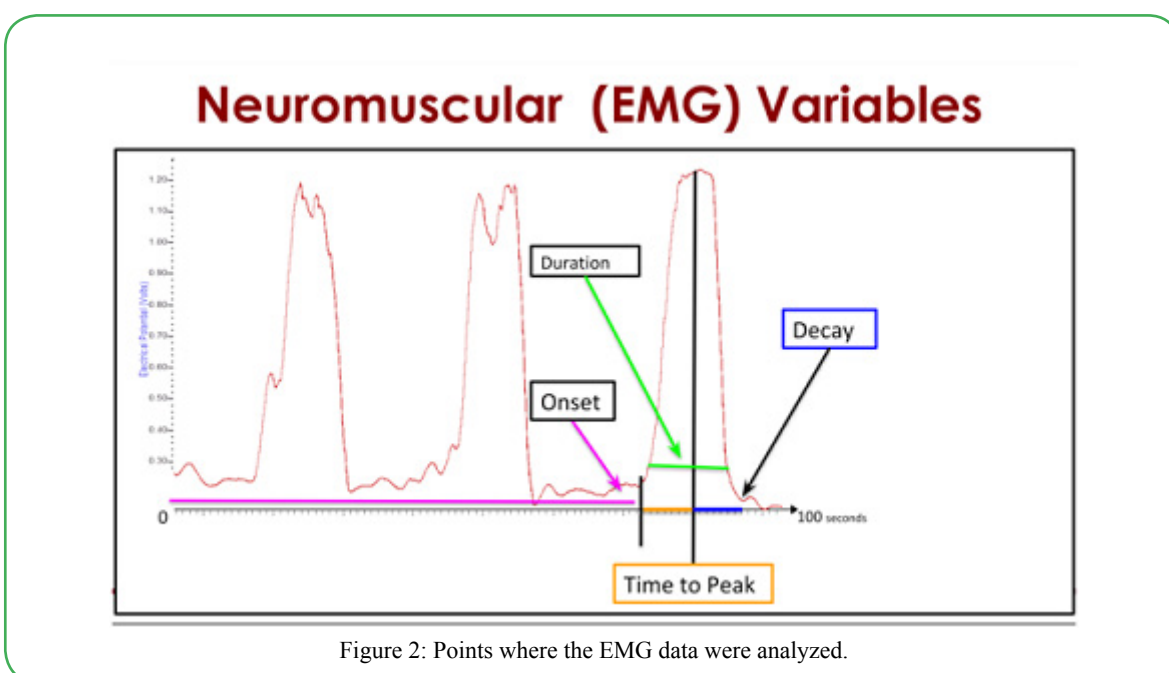
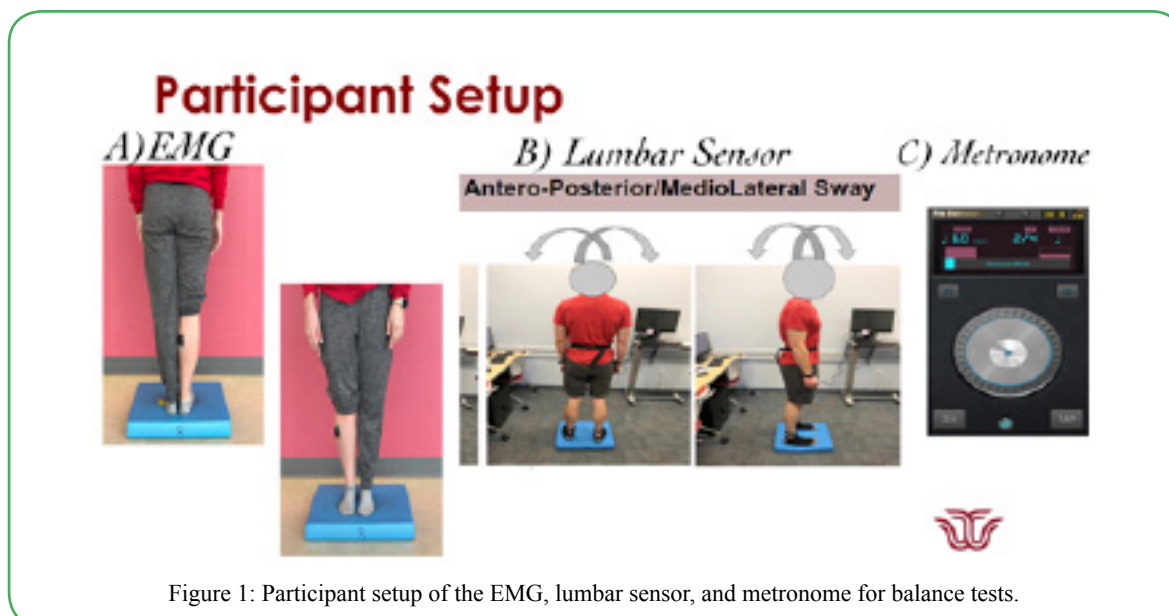
In total, participants performed eight balance tests, four prior to consuming the Edrink and four following Edrink consumption, each lasting 15 seconds. Data on postural sway and lower limb neuromuscular timing were collected.

Results

A paired sample t-test was used to compare the pre and post cardiovascular data, shown in Table 1. We defined a change in HR, BP or SpO₂ as a physiological response to consuming the energy drink, therefore using the above changes as the indication to collect post-Edrink data. Increases in all cardiovascular values were noted, except for oxygen saturation (Table 1). After Edrink intake, diastolic blood pressure exhibited the highest increase among BP (73.8+/-10.1mmHg pre-Edrink and 81.0+/-8.0mmHg post-Edrink; P=0.11), though it was not found to be significant. However, within the upper extremity, there was a significant (P<0.05) increase in HR when comparing pre-Edrink (73.2+/-14.8bpm) and post-Edrink (81.3+/-17.1bpm) data.

Since the EMG data deviated from normality, a non-parametric Friedman test combined with a post hoc analysis and Wilcoxon signed-rank test were conducted with a Bonferroni correction. Thus, this analysis was performed to adequately interpret and compare the different neuromuscular activations after energy drink consumption.

Regarding the EMG data, the highest peak activation was identified as the point of compensation or readjustment with the highest muscle recruitment during the 15-second task. Figure 2 shows the data points analyzed within the highest muscle activation peak for both TA and GA muscles during all balance tasks. In this study, onset was defined as the starting time (in seconds) where the neuromuscular readjustment or highest muscle activation occurred. Time to peak was



the time (in seconds) to maximal muscle activation (zero to max) and decay (max to zero) was the time (in seconds) to muscle relaxation. The duration was defined as the period (in seconds) between onset and decay, which depicts the total time of the neuromuscular adaptation region.

The Wilcoxon Signed Ranks examination was performed to equate the neuromuscular variables of interest between pre-Edrink and post-Edrink consumption, of which there was a statistically significant difference between the two phases, $\chi^2(63) = 459.7$, $p = 0.001$.

While the electromyography (EMG) results did not demonstrate a plethora of statistical significance, four areas distinctly stood out from the rest. Upon further investigation, some observed trends were found when comparing the first task, eyes open while standing on foam, with the last task, eyes closed with the motor component of moving the head up and down. As seen in Table 2, the difference in the time to peak for the gastrocnemius (GA) muscle during the eyes-closed task was significantly faster ($p = 0.05$) in participants after consuming the energy drink ($1.0 \text{ sec} \pm 0.8 \text{ sec}$) comparatively to pre-drink consumption ($11.0 \text{ sec} \pm 8.7 \text{ sec}$). Table 3 shows the extended duration difference with the tibialis anterior (TA) muscle during the

eyes-open task (pre-drink $0.9 \text{ sec} \pm 0.3 \text{ sec}$; post-drink $1.3 \text{ sec} \pm 0.8 \text{ sec}$), as well as the shorter duration during the eyes-open while moving the head up and down task (pre-drink $1.5 \text{ sec} \pm 0.9 \text{ sec}$; post-drink $0.9 \text{ sec} \pm 0.5 \text{ sec}$), both of which had a p-value of 0.05. Lastly, the EMG data depicted the TA time to peak as significantly quicker ($p = 0.05$) between pre-drink consumption ($0.8 \text{ sec} \pm 0.5 \text{ sec}$) and post-drink consumption ($0.4 \text{ sec} \pm 0.3 \text{ sec}$) for the eyes-open while moving the head up and down task, as seen in Table 3.

Data from the motion accelerometers were analyzed with a repeated measure ANOVA in SPSS25 to compare the different means of anterior-posterior (AP) jerk, medial-lateral (ML) jerk, AP distance, ML distance, AP velocity, and ML velocity, as seen throughout Tables 3-9. Results from the motion accelerometers during the four balance tasks obtained from both the pre-energy drink consumption phase (pre-drink) and the post-energy drink consumption phase (post-drink) were comparable. The kinematic data showed similar stability in sway, velocity, and distance between pre and post drink consumption, regardless of the sensory system being challenged within the different balance tasks.

Task	Variables	Pre-Drink (N = 13)	Post-Drink (N = 13)	P-value
Motor	Gastrocnemius			
EO Foam	Onset (sec)	11.0±8.1	13.7±7.3	0.4
	Time to Peak (sec)	0.4±0.1	1.0±0.7	0.6
	Duration (sec)	1.1±0.6	1.8±1.1	0.1
	Decay (sec)	0.7±0.5	0.8±0.7	0.6
EC Foam	Onset (sec)	11.3±7.6	14.6±6.2	0.3
	Time to Peak (sec)	11.0±8.7	1.0±0.8	0.05
	Duration (sec)	1.7±0.8	1.6±0.7	0.6
	Decay (sec)	0.7±0.3	0.9±0.6	0.8
EO HUD	Onset (sec)	14.1±8.7	14.7±8.7	1.0
	Time to Peak (sec)	0.6±0.3	0.7±0.4	0.7
	Duration (sec)	1.2±0.7	1.5±0.7	0.2
	Decay (sec)	0.6±0.5	0.8±0.6	0.2
EC HUD	Onset (sec)	11.1±8.8	10.7±7.8	0.9
	Time to Peak (sec)	0.7±0.6	0.8±0.4	0.2
	Duration (sec)	1.7±0.9	1.5±0.7	0.7
	Decay (sec)	1.0±0.5	0.6±0.4	0.1

Table 2: Electromyographic (EMG) onset, time to peak, duration, and decay of gastrocnemius during balance tasks. Results of non-parametric Wilcoxon signed-rank tests performed between pre energy drink and post energy drink. Significance level set at $p \leq 0.05$.

Task	Variables	Pre-Drink (N = 13)	Post-Drink (N = 13)	P-value
Motor	Tibialis Anterior			
EO Foam	Onset (sec)	16.2±6.5	12.1±7.6	0.3
	Time to Peak (sec)	0.4±0.2	0.7±0.5	0.2
	Duration (sec)	0.9±0.3	1.3±0.8	0.05
	Decay (sec)	0.5±0.3	0.6±0.4	0.5
EC Foam	Onset (sec)	11.3±7.6	18.2±6.8	0.7
	Time to Peak (sec)	0.7±0.5	0.5±0.3	0.4
	Duration (sec)	1.2±0.8	0.9±0.5	0.3
	Decay (sec)	0.7±0.4	0.4±0.3	0.1
EO HUD	Onset (sec)	14.0±8.7	12.7±6.9	0.6
	Time to Peak (sec)	0.8±0.5	0.4±0.3	0.05
	Duration (sec)	1.5±0.9	0.9±0.50	0.05
	Decay (sec)	0.7±0.5	0.5±0.3	0.3
EC HUD	Onset (sec)	11.1±8.8	13.1±7.5	0.6
	Time to Peak (sec)	0.8±0.4	0.8±0.4	0.5
	Duration (sec)	1.8±0.7	1.44±0.8	0.3
	Decay (sec)	1.0±0.6	0.7±0.5	0.7

Table 3: Electromyographic (EMG) onset, time to peak, duration, and decay of tibialis anterior during balance tasks. Results of non-parametric Wilcoxon signed-rank tests performed between pre energy drink and post energy drink. Significance level set at $p \leq 0.05$.

AP Jerk (m^2/s^5)			
Task	Pre-Drink	Post-Drink	P-value
EO Foam	0.007±.01	0.006±0.01	0.9
EC Foam	0.005±.007	0.01±0.03	0.3
EO HUD	0.01±0.02	0.02±0.04	0.5
EC HUD	0.02±0.03	0.01±0.02	0.4
EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, Motor = holding a cup filled with water m=meters, s=seconds			

Table 4: Anterior-posterior Jerk during balance tasks. Results of repeated measure ANOVA between pre-energy drink and post-energy drink. Significance level set at $p \leq 0.05$.

ML Jerk (m^2/s^5)			
Motor Task	Pre-Drink	Post-Drink	P-value
EO Foam	0.005±0.01	0.01±0.03	0.07
EC Foam	0.005±0.01	0.01±0.02	0.09
EO HUD	0.01±0.01	0.02±0.03	0.07
EC HUD	0.01±0.01	0.01±0.01	0.3
EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, Motor = holding a cup filled with water m=meters, s=seconds			

Table 5: Medial-lateral Jerk during balance tasks. Results of repeated measure ANOVA between pre-energy drink and post-energy drink. Significance level set at $p \leq 0.05$.

AP Distance (m/s^2)			
Task	Pre-Drink	Post-Drink	P-value
EO Foam	0.03±.05	0.3±0.03	0.9
EC Foam	0.03±.04	0.04±0.05	0.6
EO HUD	0.04±.05	0.06±0.06	0.5
EC HUD	0.05±0.06	0.05±0.06	1.0
EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, Motor = holding a cup filled with water m=meters, s=seconds			

Table 6: Anterior-posterior distance during balance tasks. Results of repeated measure ANOVA between pre-energy drink and post-energy drink. Significance level set at $p \leq 0.05$.

ML Distance (m/s^2)			
Task	Pre-Drink	Post-Drink	P-value
EO Foam	0.02±0.02	0.02±0.03	0.5
EC Foam	0.02±0.02	0.02±0.03	0.5
EO HUD	0.02±0.02	0.03±0.04	0.4
EC HUD	0.01±0.02	0.02±0.04	0.4
EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, Motor = holding a cup filled with water m=meters, s=seconds			

Table 7: Medial-lateral distance during balance tasks. Results of repeated measure ANOVA between pre-energy drink and post-energy drink. Significance level set at $p \leq 0.05$.

AP Velocity (m/s)			
Motor Task	Pre-Drink	Post-Drink	P-value
EO Foam	0.1±.0.1	0.1±0.1	0.9
EC Foam	0.04±0.1	0.2±0.2	0.2
EO HUD	0.1±0.1	0.1±.0.1	0.6
EC HUD	0.1±0.1	0.1±0.1	0.8
EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, Motor = holding a cup filled with water m=meters, s=seconds			

Table 8: Anterior-posterior velocity during balance tasks. Results of repeated measure ANOVA between pre-energy drink and post-energy drink. Significance level set at $p \leq 0.05$.

ML Velocity (m/s)			
Task	Pre-Drink	Post-Drink	P-value
EO Foam	0.02±0.03	0.03±0.05	0.5
EC Foam	0.03±0.05	0.03±0.03	0.9
EO HUD	0.03±0.04	0.04±0.05	0.6
EC HUD	0.03±0.03	0.04±0.06	0.4
EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, Motor = holding a cup filled with water m=meters, s=seconds			

Table 9: Medial-lateral velocity during balance tasks. Results of repeated measure ANOVA between pre-energy drink and post-energy drink. Significance level set at $p \leq 0.05$.

Discussion

The purpose of this study was to identify shifts in standing posture and neuromuscular timing of Tibialis anterior and Gastrocnemius in young, healthy adults while performing several dual-motor balance tasks after consuming one 16-ounce Monster energy drink. With that intent, the detailed methodology in this work attempted to repress any variables that could potentially be considered an explanation of why changes may occur post-Edrink consumption.

In this work, we determined that the altered muscle activation timings for both the Tibialis anterior (TA) and Gastrocnemius (GA) muscles were due to the impact energy drinks have on nerve conduction. Our original hypothesis was that subjects would exhibit an alteration in (TA and GA) muscle activation timing during different balance tasks due to the effect of the energy drink beverage. With this, our main findings partially supported this hypothesis, as they depicted faster nerve conduction in 2 of the four TA tasks (Table 2) and 1 of the 4 GA tasks (Table 3). Moreover, our results suggest that as a result of energy drink consumption, the TA nerve conduction demonstrated more alteration than that of the GA.

An assumption as to why this modification on neuromuscular activation occurred is since the standing posture was upheld during the different balance tasks, results suggested the fluctuation happened at a more physiological level. For instance, ingredients such as guarana have the ability to modify the speed of muscle activation in the lower limb musculature; basic science studies have found an parallel between increased movements and guarana intake, suggesting a potential increase in nerve conduction consistent with our findings [7]. B-vitamins (B9 folic acid & B12) are known to increase nerve conduction velocity, even in patients with peripheral neuropathy, and the Monster energy drink used in our study has B-vitamins in the form of niacin, inositol, riboflavin, and B12, therefore also supporting our findings [6, 14].

We are now implored to explore the neuromuscular activation impact of other ingredients, like caffeine, B vitamins, and guarana, within different concentrations. Evidence shows caffeine can increase the velocity in which information is processed [5]; therefore, we advise future studies to focus on the quantity of caffeine and guarana within the different energy drinks and the consequence these concentrations have in neuromuscular activation and postural control.

There have been evident reductions in blood flow after the intake of just one EDrink [8]. However, given the results found from our data, we have found this argument to be inapplicable to our study. Before collecting the post-Edrink data, vitals were collected from participants and were monitored for an alteration in HR, BP, or SpO₂. The average time before seeing the desired cardiovascular reaction to the energy drink was 9.8±3.1 minutes. Immediately after this modification, sway and neuromuscular activation were recorded, and lower limb oxygen saturation and heart rate were monitored (second toe of the dominant foot) following the intake of the energy drink, as seen in Table 1. An unexpected finding of this study was the unaltered lower limb HR and SpO₂ after Edrink intake, suggesting a constant blood flow, at least within our assessment period.

The noticeable adaptation in cardiovascular values occurred in the upper extremities with heart rate, where the pre-Edrink values (73.2±/-14.8 bpm) were significantly increased in comparison to post-Edrink data (81.3±/-17.1bpm). This increased HR and slightly increased diastolic BP were the physiological responses suggesting the onset of the Edrinks effectivity. Future studies should encompass muscle activation reaction time with more demanding activities, such as jumping or running. Demanding tasks would provide more data on the effects of Edrinks on muscle activation with more functional activities versus that of static standing.

According to our results, a faster time to peak activation might be beneficial, especially in activities requiring quick reaction times. However, we can speculate that when maintaining it for an extended period of time, this faster activation could provoke a quicker onset for fatigue. Future studies should focus on the beginning of muscle fatigue in activities that employ the use of this musculature for a longer duration.

In terms of postural balance, the methodology used in this study was designed to challenge all balance systems, visual (closing the eyes), somatosensory (unstable foam surface), and vestibular (head movements). With this, we hypothesized that following the consumption of the given energy drink, participants would display an increase in postural sway linked to the complexity of the task. In a normal balance system, sensory postural compensation is achievable due to sensory reweighting, allowing a shift of the importance or recruitment of a specific sensory system when the others are challenged, enabling the preservation of postural stability [15].

Despite the theoretical motor control complexity that we believed existed between postural stability and dual tasks while under the influence of energy drinks, we reject this hypothesis; the pre-energy drink and post-energy drink motion accelerometer data explicitly demonstrates comparable results, lacking statistical significance among them ($p < 0.05$).

Similarly to our results, Kim et al. [16] found stable postural sway reaction as a result of measuring postural control during eyes open, eyes closed, and different bases of support after an approximate intake of 73 mg of caffeine. We have one conjecture as to why postural sway is preserved, being the age and health status of the participant, as we conceive that participants were able to recover and adjust their sway regardless of the challenges of the balance tasks [17]. As seen in previous studies, an increased sway was observed when the balance system was challenged, however, it was not found to be significant [17, 18].

The mediolateral sway similarities in this study could be an indication that the study participants used proximal joints and limbs for balance, including the trunk and hips, rather than distal joints, such as the ankles. The medial-lateral postural sway alteration could be attributed to a central nervous system modification [19, 20]. As corroborated by Shumway-Cook and Woollacott [19], given that the balance systems are modulated in higher centers and there is evidence that Edrinks can alter complex motor patterns [21], we propose finding kinematic sway and neuromuscular activation

assessment in proximal areas, such as the trunk, to be instrumental to further comprehending the effects of Edrinks. Additionally, we find agreeable in regard to increasing the quantity of energy drinks and researching other ingredients within different energy drink blends for future studies. Lastly, we advise exploring the effects of Edrinks on neuromuscular activation in other populations who are endangered for falls, such as older adults.

Conclusion

As there was no evidence of significant change for postural balance between pre-energy drink intake and post-energy drink consumption, and taking into consideration the limitations of this work, additional data approaches and future studies are needed to comprehensively understand the impact energy drinks have on postural sway and neuromuscular activation.

While conducting this work, we encountered several limitations. Firstly, the methods of this study were specifically detailed with the intent to unmask postural and neuromuscular changes related to energy drinks. Due to this, only 13 participants were recruited to partake in this study. Secondly, although we required participants to avoid the intake of any stimulants, such as caffeine and/or energy drinks, the setting subjects were recruited from was a graduate school, with graduate students being a population known for their familiarity and regular usage of this beverage. We recommend recruiting participants with a seven day cleanse of any stimulant that can potentially express more candid reactions to Edrinks. Thirdly, as previously mentioned, it is possible that the standing postural tasks in this study were not challenging enough for a motor adjustment to provoke postural modifications from the Edrink. We recommend researching the consequence of Edrinks on activities like single leg balance, gait, pushing a sled, or a validated submaximal cardiovascular test.

This work ushers on further exploration regarding the influence of energy drinks and nerve conduction on lower extremity postural muscles. The Anterior Tibialis and Gastrocnemius muscles were analyzed, showing slower gastrocnemius activation and quicker anterior tibialis activation following the consumption of an energy drink for both the simplest and most complex of the given tasks. Additionally, the Tibialis anterior showed more signs of adaptations to the effects of the energy drinks in comparison to the Gastrocnemius. We maintain the reduced cross-sectional ratio of the muscle compared to Gastrocnemius is why these results were shown. Studies exploring injuries or pathologies, including diabetic foot or HIV peripheral neuropathy of the Tibialis anterior, could be the next step to understanding the mechanisms behind this nerve conduction adaptation. Finally, future studies could benefit from researching the onset of muscle fatigue with measures on neuromuscular activation timing and lactate levels.

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