Journal of Sports Research
2022 Vol. 9, No. 2, pp. 101-111.
ISSN(e): 2410-6534
ISSN(p): 2413-8436
DOI: 10.18488/90.v9i2.3153
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THE INFLUENCE OF ENERGY DRINKS ON LOWER LIMB MUSCLE FATIGUE AND RECOVERY IN HEALTHY YOUNG ADULTS

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Article History
Received: 25 July 2022
Revised: 8 September 2022
Accepted: 23 September 2022
Published: 5 October 2022

Keywords
Energy drink ingredients
Motor control
Muscle delay
Muscle fatigue
Static balance.

ABSTRACT

Many studies have researched the influences of energy drinks (Edrinks) on the central nervous system, balance, and neuromuscular control. Understanding the neuromuscular adaptations that occur after drinking Celsius Edrinks on muscle fatigue and balance can be helpful when advising the use of Edrinks during physical activity. This study aims to understand the impact Celsius Edrinks has on neuromuscular adaptations in lower limb musculature during muscle fatigue, and balance in young, healthy adults. Two males and eighteen females were recruited for this study. The tibialis anterior, gastrocnemius, and Gluteus Medius neuromuscular data were captured with surface EMG electrodes. The number of single-leg heel raises repetitions and time to fatigue were recorded. Subjects were asked to perform single-leg heel raises to fatigue and single-leg balance activities pre-energy drink consumption, and the same tasks were repeated on the opposite not tested limb (post Edrinks consumption) to equate data points. Neuromuscular timing data suggested modifications on leg musculature. Although not significant, the amount of single-leg heel raises performed pre, and post-drink intake increased post-energy drink consumption. We infer that the ingredients in Celsius energy drinks, including caffeine, Taurine, and Guarana, alter nerve conduction velocity in lower limb musculature during exercise and balance activities. Future studies should research the influence of Celsius energy drinks in different scenarios and populations.

Contribution/Originality: This work's main contribution is identifying minimal neuromuscular adaptations to a fatigue test after celsius energy drinks intake in healthy young adults. Particularly, this investigation identified trends towards nerve conduction velocity variations during exercises and balance activities associated to the different ingredients in said drink such as caffeine.

1. INTRODUCTION

An Energy Drink is a beverage typically containing stimulant ingredients, caffeine, and other additional dietary supplements. Energy drinks (Edrinks) are commonly marketed as products that boost energy by improving mental alertness and physical performance. In 1949, the first energy drink appeared in the United States after a chemist in Chicago created Dr. Enuf. However, energy drink popularity didn't take off until RedBull arrived in the United States in 1997. Since then, multiple brands have risen on the market; global energy drink sales reached $57.4 billion

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in 2020. The industry is expected to grow by a compound annual growth rate of 7% between 2020 and 2025 (Fontinelle, 2021). The issue is these beverages have been under the spotlight since they started gaining popularity. According to Harvard T.H. Chan School of Public Health, Energy Drinks may increase the risk of various health issues, such as poor mental health, tooth decay, diabetes, and high blood pressure. The Drug Abuse Warning Network report calculates that an energy drink includes 80 to 500 milligrams of caffeine, contrasted to about 100 mg in a 5-ounce cup. According to the Food and Drug Administration (FDA), the recommended amount of caffeine not associated with negative side effects is 400 mg daily. Studies have tied energy drinks to negative effects on the cardiovascular system, such as abnormal heart rhythms. It was also tied to an increase in blood pressure and the release of catecholamines, a stress hormone released by the adrenal gland. These hormones are considered a risk factor for cardiovascular complications (Svatikova et al., 2015). Regardless of the documented difficulties, The National Center for Complementary and Integrative Health declared that energy drinks are the most outstanding dietary supplement consumed by teens and young adults in the United States after multivitamins (NCCIH, 2018).

On the other hand, some of the ingredients such as Taurine, an amino acid found in most energy drinks, whose occurrence in these beverages is similar to caffeine, are associated with positive outcomes (Yunusa & Ahmad, 2012). Taurine improves endurance and reduces lactic acid build-up post-exercise. It also helps with nerve growth and is thought to activate the parasympathetic, leading to a decrease in heart rate. Some brands of energy drinks have Taurine as one of their ingredients, which significantly increased upper body muscle endurance (Forbes, Candow, Little, Magnus, & Chilibeck, 2007). An additional benefit of energy drinks is the correlation with favorable performance during physical activity. A randomized control trial tied Celcius energy drink to a decrease in fat mass and percentage of body fat and increases in VO2peak when used in conjunction to exercise (Lockwood et al., 2010). Another study showed significant improvements in time to exhaustion for endurance performance, which was on average 24.2% over controls, and the rate of perceived exertion was also lower in people who drank coffee. Higgins, Tuttle, and Higgins (2010). Some studies pointed out that consumption of 16oz of energy drinks causes an increased tendency to postural instability after consuming 16oz of energy drinks (Rosario, Collazo, Mateo, Gonzalez-Sola, & Bayron, 2017). Additionally, Rosario, Jamison, and Hyder (2020); Rosario, Clare, Lauren, and Ashley (2021) in their study, mentioned that energy drinks created neuromuscular adaptations in lower limb musculature (2020, 2021a) and gait modifications (2021b). The current study examines the effects of Celsius energy drinks on neuromuscular adaptation in the lower limb during muscle fatigue. Celsius beverages are gaining popularity among students by offering a healthier alternative with no sugar and no preservatives (https://www.celsius.com/). Celsius caffeine content is above average compared to most energy drinks, with 200mg per serving. Celsius advertised its science as backed by college studies showing that the drink can help reduce body fat and increase peak VO2 Max (Lockwood et al., 2010). Our study investigates the role of Celsius in lower limb neuromuscular adaptations during balance and muscle fatigue. We hypothesized that Celsius would provoke minimal neuromuscular change after muscle fatigue in young, healthy individuals.

2. METHODS

2.1. Participants

Participants were recruited by convenience sampling at Texas Woman's University (TWU) - Dallas campus. Twenty total subjects (18 females and 2 males) participated in this study, with a mean age of 23.25 (+/- 1.59 years, Table 1a) and a BMI of 25.91 (+/- 4.93, Table 1a).

2.2. Study Criteria

*Inclusion Criteria: H*ealthy participants were recruited from both genders at TWU between the ages of 22 and 28. This particular age range was selected based on the popularity of Edrinks among college students (Burrows, Pursey, Neve, & Stanwell, 2013).

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Exclusion Criteria: Participants were excluded if they met any of the following criteria: allergy to any ingredients in Celsius energy drinks, or participants reported unwanted side effects following energy drink consumption in the past.

2.3. Procedures

The IRB approved this study, and all participants signed the informed consent before testing and screening. Subjects eligible to participate in the study were instructed to withhold the ingestion of stimulants, including coffee and/or energy drinks, for at least 12 hours prior to the date of data collection. At the beginning of data collection, demographic information and baseline vitals were collected. Participants' dominant leg was then determined by applying a perturbation from behind, and whichever leg was utilized during the stepping strategy was identified as the dominant leg. Muscle activation data was collected using the Delsys, Inc surface electromyography (EMG) system. The EMG surface electrodes were placed on the participants' Tibialis Anterior (TA), Gastrocnemius (GA), and Gluteus Medius (GMED) muscles. The subjects were randomly instructed which leg to place the sensors on first, to prevent every subject from placing the sensors on their dominant leg first. Balance data was collected using the Opal Mobility Lab system. The Mobility Lab sensors were placed around the participants' ankles, wrists, and lumbar spine.

Pre-Energy Drink Consumption: The subjects' baseline vitals, including heart rate, blood oxygen saturation, and blood pressure, were monitored in the resting, sitting position. Participants then had EMG electrode sensors placed on leg (tibialis anterior and gastrocnemius) and gluteal region (gluteus medius) in their proper positions. Subjects were asked to perform a maximal contraction assessment to get a baseline before the single-leg balance and muscle fatigue tests began. Before the muscle fatigue test, the subjects were then taken through the single-leg balance test.

Single leg balance test protocol: the participants were instructed to perform a single leg stance on a firm surface with eyes open for 10 seconds, and then a single leg stance on a foam surface for 10 seconds with eyes open. Next, the muscle fatigue test was conducted.

Muscle fatigue test protocol: the participants were instructed to perform as many calves raises (ankle pumps) as possible, and a metronome was used to set a consistent tempo for every participant. The subject could use two fingers to balance on a chair if needed, but was instructed not to put any weight through their fingers. The test was terminated when the subject could not complete more calf raises, if the subjects' tempo differed from the metronome, and/or if the participants' form began to deteriorate. After the muscle fatigue test, the single-leg balance test protocol was again conducted. Muscle activation was recorded using the EMG sensors, and balance data were collected using the Mobility Lab sensors.

Post-Energy Drink Consumption: Subjects consumed one 12 fl oz standard Celsius energy drink within 5 minutes. Each participant set a timer for 30 minutes after they finished their Celsius energy drink. After 30 minutes, each participant's vitals were recorded, including their heart rate, blood oxygen saturation, and blood pressure in the resting or sitting position. The EMG sensors were placed in their proper positions on the opposite leg than the one used for the pre-energy drink consumption tests. The maximal contraction assessment was repeated, and then the participants began the single-leg balance tests and muscle fatigue test protocol in the same order as pre-energy drink consumption.

Participants performed two single-leg balance tests, one muscle fatigue test before consuming an energy drink, two single-leg balance tests, and one muscle fatigue test after consuming the energy drink. Data on neuromuscular timing and strength were collected from all three muscles on both legs of every participant using the Delsys, Inc EMG system. In addition, balance data was collected on every participant using the Mobility Lab sensors during the single-leg balance tests Figure 1 summarizes the protocol.

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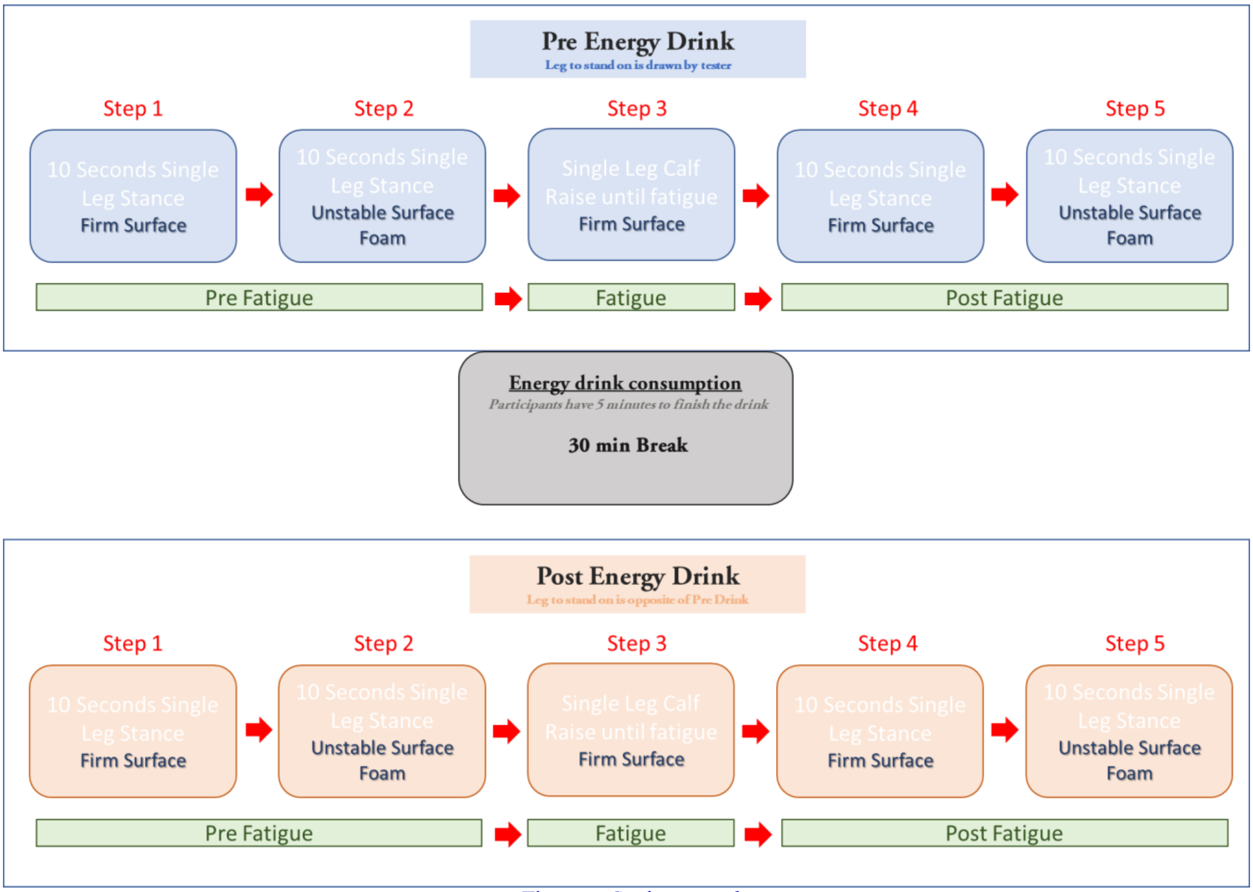

Figure 1. Study protocol.

2.4. Data Analysis

Electromyography (EMG) was recorded using a surface electrode system (Delsys, Inc. Boston, MA) and processed by EMG analysis for all muscles. The EMG activity of the gluteus medius, tibialis anterior and gastrocnemius muscles was collected at 1,000 Hz with the electrodes placed according to the previously published protocol by Rosario, Pagel, Miller, and Weber (2022). Three data points were identified during the EMG trace and chosen for each muscle during all trials. The variables of interest in this endeavor are the time to onset muscle activation (onset), time to peak activation (TP), decay from peak activation, and duration of muscle activity. The EMG data collection was an average of 3 consecutive activation points for each muscle during all trials and tasks. For the data analysis, this study utilized (Statistical Package for the Social Sciences) SPSS (version 28) with a ANOVA analysis to compare the means for neuromuscular-time variables pre and post fatigue tests. This work examined the impact of Celsius energy drink on muscle performance on all variables of interest (onset, TP, decay, and duration) by comparing single leg stand balance pre and post fatigue and additionally utilizing the same comparative approach pre and post energy drink. In this investigation, we regard a p-value of < 0.05 as statistically significant. Finally, to compare pre and post energy intake data points this study performed a t-test for the repetitions of the calf rise, time to fatigue and heart rate. A p-value of < 0.05 as statistically significant.

3. RESULTS

Table 1a contains the study's demographics, including age, sex, BMI, and height for each energy drink group. All participants were students from the TWU Dallas physical therapy program. Females made up the largest population in this study: 18 females compared to 2 males. Each participant went through the same protocol. The average age of participants was 23.25 +/- 1.59, the average body mass index (BMI) was 25.91 +/- 4.93, 11 participants were right leg dominant, and nine were left leg dominant. Heart Rate (HR), blood pressure (BP), and

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oxygen saturation (O2 Sat) were measured for every participant at the beginning of the study and 30 minutes after consuming the energy drink. No participants were found to be hypertensive. However, as seen in Table 1b and Table 1c, the average heart rate for participants was lower 30 minutes after consuming the drink than at the beginning of the study. In addition, oxygen saturation was found to be within normal limits for all participants.

Table 1a. Demographic data of all participants.

Characteristics	Study Participants (n) = 20
Age	23.25 +/- 1.59 years
Gender	Male = 2; Female = 18
Height (inches)	64.75 +/- 2.63
Weight (pounds)	155.24 +/- 34.97
Leg Dominance	11 Right; 9 Left
BMI	25.91 +/- 4.93
Leg Dominance	R= 11 L=9

Table 1b. Demographic data of all participants pre drink.

Characteristics	Study Participants (n) = 20
Dominant leg tested Pre Drink	(n) = 8
Non-Dominant leg tested Pre Drink	(n) = 12
Systolic BP (mmHg) Pre Drink	121 +/- 12.48
Diastolic BP (mmHg) Pre Drink	84 +/- 9.23
O2 Sat (%) Pre Drink	98 +/- 0.87
Heart Rate (BPM) Pre Drink	86 +/- 13.358

Table 1c. Demographic data of all participants post drink.

Characteristics	Study Participants (n) = 20
Dominant leg tested Post Drink	(n) = 12
Non-Dominant leg tested Post Drink	(n) = 8
Systolic BP (mmHg) Post Drink	124.85 +/- 11.4
Diastolic BP (mmHg) Post Drink	87.2 +/- 9.13
Sat O2 (%) Post Drink	98.53 +/- 0.96
Heart Rate (BPM) Post Drink	78 +/- 10.54

Table 2a compares EMG timing (seconds) for GMED, GA, and TA during Single Leg Balance on Firm Surface Pre-Edrink and Pre/Post Ankle Pumps. Results of a MANOVA were performed to compare all variables. The significance level was set at p≤0.05.

Glut Med	Firm Surface, Pre-Edrink, and Pre-Ankle Pumps Means and SD	Firm Surface, Pre-Drink and Post-Ankle Pump Means and SD	P-Value
Onset	7.719 +/- 0.377	7.520 +/- 0.269	0.192
TP	0.260 +/- 0.126	0.313 +/- 0.068	0.252
Decay	0.301 +/- 0.071	0.330 +/- 0.136	0.550
Duration	0.561 +/- 0.159	0.644 +/- 0.113	0.195
Gastroc	Means and SD	Means and SD	P-Value
Onset	8.163 +/- 0.242	7.568 +/- 0.335	<0.001
**TP	0.510 +/- 1.059	0.399 +/- 0.133	0.745
Decay	0.326 +/- 0.099	0.279 +/- 0.087	0.272
Duration	0.057 +/- 0.961	0.678 +/- 0.189	0.737
Tibialis Ant	Means and SD	Means and SD	P-Value
Onset	7.702 +/- 0.383	7.594 +/- 0.437	0.562
**TP	0.347 +/- 0.138	0.340 +/- 0.107	0.893
Decay	0.396 +/- 0.219	0.676 +/- 1.108	0.443
Duration	0.743 +/- 0.311	0.260 +/- 1.331	0.279

Note: ** TP = Time to peak.

Table 2a compared the EMG timing between the GMED, GA, and TA during single-leg balance on a firm surface before the energy drink was consumed. Table 2b compared the EMG timing between those same muscles during the single-leg balance on a foam surface before consuming the energy drink. The results of a MANOVA are shown in Table 2a and 2b to compare all variables, with the significance level set at $p \leq 0.05$. One finding within

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Table 2a was statistically significant; the onset of the GA muscle activation changed from 8.163 +/- 0.242 to 7.568 +/- 0.335, resulting in a p-value of <0.001. There were no other statistically significant values noted in Table 2a. Likewise, in Table 2b, no data was statistically significant. However, there were a few trends observed near significant values. The first trend was found in the GMED decay, which changed from 0.323 +/- 0.131 to 0.213 +/- 0.121, resulting in a p-value of 0.068. The second trend was found during the onset of TA, which changed from 7.272 +/- 0.519 to 7.638 +/- 0.302, resulting in a p-value of 0.070.

Table 2b. EMG timing (seconds) comparisons for GMED, GA, and TA during single leg balance on foam surface Pre-Edrink and pre/post Ankle Pumps. Results of a MANOVA were performed to compare all variables. The significance level was set at p≤0.05.

Glut Med	Foam Surface, Pre-Edrink, and Pre-Ankle Pumps Means and SD	Foam Surface, Pre-Drink and Post-Ankle Pump Means and SD	P-Value
Onset	7.458 +/- 0.619	7.669 +/- 0.260	0.332
**TP	0.311 +/- 0.120	0.318 +/- 0.138	0.912
Decay	0.323 +/- 0.131	0.213 +/- 0.121	0.068
Duration	0.634 +/- 0.201	0.531 +/- 0.236	0.305
Gastroc	Means and SD	Means and SD	P-Value
Onset	7.408 +/- 0.834	7.670 +/- 0.260	0.357
TP	0.283 +/- 0.131	0.364 +/- 0.207	0.308
Decay	0.556 +/- 0.230	0.437 +/- 0.231	0.263
Duration	0.839 +/- 0.342	0.801 +/- 0.392	0.820
Tibialis Ant	Means and SD	Means and SD	P-Value
Onset	7.272 +/- 0.519	7.638 +/- 0.302	0.070
**TP	0.356 +/- 0.272	0.357 +/- 0.210	0.996
Decay	0.359 +/- 0.312	0.350 +/- 0.132	0.930
Duration	0.715 +/- 0.566	0.706 +/- 0.241	0.964

Note: ** TP = Time to peak.

Table 3a. compares EMG timing (seconds) for GMED, GA, and TA during single leg balance on firm surface Post-Edrink and Pre/Post Ankle Pumps. Results of a MANOVA were performed to compare all variables. The significance level was set at p≤0.05.

Glut Med	Firm Surface, Post-Edrink, and Pre-Ankle Pumps Means and SD	Firm Surface, Post-Drink and Post-Ankle Pump Means and SD	P-Value
Onset	7.527 +/- 0.244	7.704 +/- 0.417	0.262
**TP	0.264 +/- 0.083	0.297 +/-0.157	0.564
Decay	0.313 +/- 0.130	0.265 +/– 0.136	0.439
Duration	0.576 +/- 0.176	0.555+/- 0.264	0.829
Gastroc	Means and SD	Means and SD	P-Value
Onset	7.869+/-0.350	7.7+/-0.296	0.249
TP	0.145+/-0.149	0.353+/-0.091	0.001
Decay	0.299+/-0.114	0.430+/-0.202	0.091
Duration	0.353+/-0.220	0.783+/-0.219	<0.001
Tibialis Ant	Means and SD	Means and SD	P-Value
Onset	7.564+/-0.409	7.413+/-0.342	0.384
**TP	0.276+/-0.120	0.324+/-0.185	0.516
Decay	0.238+/-0.086	0.268+/-0.185	0.632
Duration	0.412+/-0.146	0.592+/-0.260	0.408

Note: ** TP = Time to peak.

Table 3a compared the EMG timing between the GMED, GA, and TA during single-leg balance on a firm surface after consuming the energy drink. Table 3b compared the EMG timing between the same muscles during single-leg balance on a foam surface after energy drink consumption. The results of a MANOVA are shown in Table 3a and 3b to compare all variables, with the significance level set at $p \leq 0.05$. In Table 3a, there were two statistically significant findings. The first trend was found during the time it took for the GMED muscle activity to peak, which changed from 0.145 +/- 0.149 to 0.351 +/- 0.091, resulting in a p-value of 0.001. The next trend was discovered in GA's duration, which changed from 0.353 +/- 0.220 to 0.783 +/- 0.219, resulting in a p-value of <0.001. In Table 3b, there were no statistically significant trends noted.

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Table 3b. EMG timing (seconds) comparisons for GMED, GA, and TA during single leg balance on foam surface Post-Edrink and Pre/Post Ankle Pumps. Results of a MANOVA were performed to compare all variables. The significance level was set at p≤0.05.

Glut Med	Foam Surface, Post-Edrink, and Pre-Ankle Pumps Means and SD	Foam Surface, Post-Drink and Post-Ankle Pump Means and SD	P-Value
Onset	7.555+/-0.371	7.61+/-0.256	0.704
**TP	0.335+/-0.184	0.320+/-0.121	0.832
Decay	0.242+/-0.132	0.244+/-0.147	0.975
Duration	0.576+/-0.268	0.563+/-0.219	0.907
Gastroc	Means and SD	Means and SD	P-Value
Onset	7.487+/-0.287	7.610+/-0.256	0.325
**TP	0.286+/-0.139	0.288+/-0.190	0.979
Decay	0.673+/-1.088	0.356+/-0.140	0.372
Duration	0.865+/-0.873	0.644+/-0.191	0.445
Tibialis Ant	Means and SD	Means and SD	P-Value
Onset	7.483+/-0.302	7.599+/-0.365	0.449
**TP	0.264+/-0.119	0.363+/-0.146	0.115
Decay	0.251+/-0.141	0.356+/-0.226	0.226
Duration	0.515+/-0.237	0.719+/-0.331	0.129

Note: ** TP = Time to peak.

Table 4 compared the EMG timing between the GMED, GA, and TA during the muscle fatigue test (ankle pump activity) before and after energy drink consumption. The results of a MANOVA were performed to compare all variables, and the significance level was set at $p \leq 0.05$. There were no statistically significant trends found in Table 4.

Table 4. Comparisons of EMG timing (seconds) for GMED, GA, and TA during Ankle pump activity pre-post Edrink. Results of a MANOVA were performed to compare all variables. The significance level was set at p≤0.05.

Glut Med	Pre-Edrink during Ankle Pumps Means and SD	Post-Drink during Ankle Pump Means and SD	P-Value
Onset	4.967 +/-0.943	5.224+/-1.206	0.602
**TP	0.049+/-0.024	0.05+/-0.028	0.900
Decay	0.058+/-0.028	0.074+/-0.039	0.323
Duration	0.106+/-0.042	0.073+/-0.04	0.458
Gastroc	Means and SD	Means and SD	P-Value
Onset	4.737+/-1.099	5.016+/-1.302	0.612
**TP	0.053+/-0.020	0.005+/-0.155	0.345
Decay	0.104+/-0.023	0.163+/-0.161	0.268
Duration	0.157+/-0.017	0.168+/-0.022	0.227
Tibialis Ant	Means and SD	Means and SD	P-Value
Onset	4.967+/-1.024	5.171+/-1.340	0.709
**TP	0.049+/-0.012	0.054+/-0.02	0.510
Decay	0.072+/-0.042	0.098+/-0.052	0.236
Duration	0.121+/-0.04	0.151+/-0.048	0.132

Note: ** TP = Time to peak.

Table 5 compared the number of calf raises performed to fatigue before and after energy drink consumption. As well as the time it took the participant to fatigue before and after consuming the energy drink. This table also compares the heart rate recorded for participants at the beginning of the study to the heart rate recorded 30 minutes after consumption of the energy drink. Results of a T-Test were performed to compare all variables, and the significance level was set at $p \leq 0.05$. In Table 5, the heart rate changes were statistically significant. The heart rate went from 86 +/- 13.358 to 78 +/- 10.548, resulting in a p-value of 0.002. One other finding was observed to be near significant value. The number of repetitions of calf raises fatigue to 33 +/- 6.609 to 35.5 +/- 8.976 after the energy drink, resulting in a p-value of 0.069.

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Table 5. Comparisons of the amount of calf raises performed before, time to fatigue, and heart rate; pre and post-drink. Results of a T-Test were performed to compare all variables. The significance level was set at p≤0.05.

Variable	Pre Drink Mean and SD	Post Drink Mean and SD	P-Value
# Repetitions of the calf rise to fatigue	33 +/-6.609	35.5 +/-8.976	0.069
Time to fatigue	58 +/-13.235	62.25 +/-17.961	0.102
Heart Rate (bpm)	86+/-13.358	78+/-10.548	0.002

4. DISCUSSION

This study examined Celsius's role in lower limb neuromuscular adaptations during balance tasks and muscle fatigue. We hypothesized that Celsius would provoke minimal neuromuscular adaptation due to muscle fatigue in young, healthy individuals. Results showed a reduced adaptation of the studied muscles after drink intake; however, not significant. Based on the findings, we partially accept our hypothesis.

Our *first* finding showed similarities in neuromuscular adaptations after consuming the Celsius beverage during post-fatigue balance tasks. It seems that energy drinks did not significantly affect muscle activation during exercise and balance activities. This same trend of similarities in muscle activation was noted in the ankle musculature during balance activities after consuming an energy drink (Rosario, Clare, Lauren, & Ashley, 2021a). However, unlike Rosario et al. (2021a) in the current study, the duration of muscle activation changed after the fatigue test before consuming the Edrinks. During firm surface balance, it tended to show that all three muscles, Tibialis Anterior, Gastrocnemius, and Gluteus Medius, adapted by increasing their duration frequency. Additionally, the relationship mentioned above was inverted during the foam balance test. A trend for a longer duration was discerning in post than pre-fatigue tests (prior Edrink intake). Analogous determinations were found in a study by Correa, Hanrahan, Basye, and Rosario (2021) which identified a trend to reduce jerk movement (postural sway) in altering more extended muscle activation after consuming a Red Bull drink.

The above discoveries indicated that, although not substantial, the Celsius drink preserved the muscle from changes in neuromuscular timing elicited by muscle fatigue during the balance tasks. These modifications in the duration of muscle activation suggest that Celsius or some ingredients (Caffeine or Guarana) shorten reaction time during balance exercise post fatigue. These findings coincide with a study by Concerto et al. (2017) which indicates that caffeinated drink consumption has various benefits post exercises, such as reducing intracortical facilitation, shortened simple reaction time, and enhanced pre-movement facilitation and post-exercise facilitation. Celsius also contains guarana as an ingredient, as mentioned by Rosario et al. (2021a). Guarana has been reported as a component that could improve alertness, reaction time, speed of information processing, and physical performance. Based on our results, we speculate that elements such as guarana could help preserve neuromuscular integrity post-fatigue in lower limb musculature as suggested by previous studies (Concerto et al., 2017; Rosario, Hogle, & Williams, 2021b). However, additional studies are needed to distinguish how these ingredients in isolation impact standing posture and muscle activation during exercise and balance activities. The second determination of this study was revealed in Table 5, as the number of ankle pumps (calf raise) repetitions performed by participants increased from pre to post-consumption of the energy drink. Although not significant, neurochemical adaptations can partially explain these increased repetitions after Edrinks intake. As mentioned in a systematic review by Elena Barceló Cormano (2019) the effect of caffeine on fatigue is based on brain neurochemical changes that modify perceived exertion during exercise and reduce the sensation of pain. Therefore, the perceived exertion after the fatiguing activity adapted allowing participants to perform a great number of repetitions. Another explanation for the previous outcomes could be that 12 participants had their dominant leg tested post drink, which could explain the ability to perform a higher number of calf raises before fatigue. Although the current study randomized the starting limb, it's still possible that testing the dominant leg post-drink could have altered our results since the dominant leg is more muscular and, therefore, stronger (Lanshammar & Ribom, 2011). However, the current study based the randomized limb protocol on the previously established understanding that postural adaptations during

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single limb support are similar in both extremities regardless of their dominance (Bowman & Rosario, 2021). Nevertheless, the current study proposes that future examinations should consider testing the same limb pre and post-energy drink consumption; however, permitting adequate rest between sets.

The third outcome revealed that TPs frequency of neuromuscular timing was more evident in leg musculature than in hip. The prior statement points to the expected leg being driven into fatigue with the ankle pump test compared to a hip muscle. The primary role of the gluteal musculature was maintaining the hip aligned during a single-leg stance. Contrary to the hip muscle, research has shown that tibialis anterior and peroneus longus, also known as fibularis longus, showed the highest electromyography at the ankle musculature during balance activities on stable and unstable surfaces (Ferreira et al., 2011). The fibularis longus (FL) muscle is the primary everter of the forefoot. It plays an important role in the ankle joint during movement, by stabilizing the joint in the frontal plane to avoid unwanted inversion during ankle pumps (Sperber, 2006). This muscle also plays an important role in providing proprioceptive feedback regarding the ankle position. One study concluded that the fibularis longus muscle sends the primary afferent input to the brain, which helps maintain balance, even more than the ligamentous structures of the ankle (Fraser, Feger, & Hertel, 2016). Based on the role of the FL in standing balance, it is possible that the FL could have shown neuromuscular change during the fatigue test, which the current study missed since it erred in measuring the FL during the balance test. Therefore, future studies should also record the EMG activity of the fibularis longus during balance tasks and fatigue activities.

The final discovery in Table 5 revealed a significant difference with a drop in heart rate for participants after consuming the energy drink. While not akin to our study, we thought the consumption of Celsius could explain this drop in heart rate. During a previous study, it was found that the consumption of energy drinks contributes to a heart rate decline (Hajsadeghi et al., 2016). In contrast, other studies have found that consuming Red Bull energy drinks increases heart rate and blood pressure Grasser, Yepuri, Dulloo, and Montani (2014). Higgins et al. (2010) report that ingredients such as Ginkgo Biloba and L-Carnitine cause a vasomotor and circulatory effect and increase oxygen consumption, explaining the drop in heart rate. However, energy drinks are also associated with a reduction in flow-mediated dilation of arteries and endothelial dysfunction, among others (Higgins, 2013); (Higgins et al., 2017). Prospective inquiries should look at the effects Celsius has on heart rate and electrical activity of the heart via Electrocardiogram (ECG) at multiple intervals to adequately understand its potential cardiac effects.

5. CONCLUSION

This study aimed to investigate the impact of Celsius energy drinks on neuromuscular adaptations due to muscle fatigue and single-leg balance tests. There was no significant change in muscle fatigue between pre- and post-energy drink consumption. Nevertheless, prolonged muscle activation was noted post-drink and post fatigue test during single balance activity. This adaptation could be interpreted as a proactive neurological response and pre-movement facilitation after consuming Celsius. Another notable trend included the participants being able to do more calf raise repetitions after consuming the energy drink. This tendency could be interpreted as the energy drink affecting muscle fatigue. However, as mentioned above, future studies will need to be conducted to determine if the energy drink delayed muscle fatigue or if this was a neurochemical adaptation to the drink.

Further investigations and alternative data approaches are needed to comprehensively understand the impact Celsius and other energy drinks have on muscle fatigue due to some limitations within the study. One limitation was that the EMG sensors only recorded muscle activation of the gluteus medius, tibialis anterior, and gastrocnemius muscle. Forthcoming studies should contemplate recording EMG activity of the fibularis longus, because this muscle activity plays a critical role in ankle stability. In addition, this study tested different limbs pre and post-drink in each participant to avoid alterations to our findings due to direct fatigue. Prospective studies should test the same limb pre and post-drink, but allow substantial rest between tests. Based on our results, we recommend assessing the same dominant limb before and after energy drink consumption. Participants should have

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5 minutes to drink their energy drink, and then a 30 min break, before continuing the post-energy drink testing. The 30 min break should be adequate time to enable the energy drink to take full effect, and the muscle fibers on the dominant leg to recover for the next muscle fatigue test. As a final note, the role of Celsius and muscle fatigue could be assessed with vigorous activities, such as running or pushing a sled.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

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