

Effects and Effectiveness of Energy Drinks

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Abstract – There are two purposes of this paper. The first is to validate or invalidate the marketing claims of the effectiveness of Red Bull and coffee. The second is to evaluate the health risks associated with consuming products classified as energy drinks. This study is significant due to current daily consumption level among teens and adults. Using a hybrid of extensive research and our own experimentation, we will determine that energy drinks are both effective in increasing performance of the consumer and unlikely to cause immediate harm, but are not healthy and should not be consumed on a regular basis. The present research was conducted in a semester-long sophomore-level biomedical engineering course of physiology for engineers.

Keywords: Energy drinks, validation, taurine, caffeine, health

INTRODUCTION

The substances assessed in this paper are Red Bull and coffee, the two most commonly ingested energy drinks. In order to determine whether these energy drinks are safe for consumption and can deliver the promised effect, we will evaluate existing research and conduct an experiment. The present research was conducted in a semester-long sophomore-level biomedical engineering course of physiology for engineers.

Red Bull is the most popular new-age energy drink, and is increasing in popularity among teens and young adults. Coffee, however, is the traditional energy-providing beverage. Adults have been consuming coffee for years in search of its energizing effects.

Following Red Bull's popularity, questions were raised about the drink's possibly dangerous side effects. "The Associated Press also reports that 677 cases of energy drink overdoses and side effects were noted from October through December 2010... most of which involve children and teens"[10]. This comes after the European Food Safety Authority (EFSA) concluded that the key ingredients in energy drinks (taurine and glucuronolactone) are safe in the levels used in Red Bull in 2009 [10].

Objectives:

The purpose of this paper is to study the effects and effectiveness of energy drinks through research and experimentation. We will evaluate effectiveness by comparing experimental results to the marketing claims. We will determine the effects by analyzing the ingredients found in most energy drinks. If we find that energy drinks are safe for consumption, then our goal is to compare Red Bull and coffee for safety and effectiveness. We will then find how much of each drink is safe to consume per day.

Marketing Claims:

Red Bull became the first energy drink on the market when it was released in 1987. Red Bull claims to vitalize the body and mind during any situation [30]. The drink's website declares it increases performance, concentration and reaction speed, improves vigilance, stimulates metabolism, and makes one feel more energetic therefore improving overall well-being. The drink is usually marketed to college students and those who participate in extreme sports, but claims to be useful for anyone who wants to be mentally and physically active.

Coffee is the most widely used and best known energy-providing drink. Coffee has become as much a part of American culture as it has a crutch for most adults who do not get enough sleep. New studies have found that coffee does not raise blood pressure or cholesterol, may have anti-cancer properties, reduces likelihood of developing diabetes, and helps to protect men against Parkinson's disease [12]. However, it is also widely known that coffee can be very addictive, due to the high levels of caffeine it contains. Starbucks branded Frappuccino coffee beverage was used as a coffee model during research and experimentation because of its more uniform and readily available information. The drink contains brewed coffee, reduced fat milk, sugar, and preservatives. It contains 75mg of caffeine, which is slightly less than average for a cup of coffee.

Table 1: Ingredients

	Red Bull	5-Hour Energy	Coffee (Frappuccino)
Caffeine	80mg	Yes	75mg
Taurine	~1g	Yes	No
Glucuronolactone	Yes	Yes	No
B-vitamins	Yes	In Excess	No
Calories	110	4	200
Carbs	28g	n/a	37g
Sugars	27g	0	32g

Caffeine is a bitter substance that is ingested on a daily basis everywhere around the world whether in the form of a soft drink, coffee, or chocolate. It is a stimulant of both psychological and physiological functions. It effects the body's metabolism and stimulates the central nervous system. Caffeine is said to increase reaction speed, vigilance, the ability to concentrate, and problem solving abilities. It is known to help decrease mental fatigue when studying, working or during extended physical activity. It can also help burn fat stored in the body when ingested during physical activities.

Table 2 [30]Caffeine in drinks

CAFFEINE AMOUNTS IN DIFFERENT BEVERAGES		
	Average per serving	Range
Average cup of dripped coffee (250 ml)	127 mg	74-185 mg
Average cup of instant coffee (250 ml)	84 mg	63-105 mg
Average cup of tea (250 ml)	58 mg	21-95 mg
Average cup of cocoa beverage (250 ml)	19 mg	3-34 mg
Regular cola drink (400 ml)	45 mg	40-52 mg
Red Bull Energy Drink (250 ml)	80 mg	-
Plain bar of bitter chocolate (100 g)	73 mg	18-127mg

One serving of Red Bull (250ml) contains 80mg of caffeine, while 250ml of dripped coffee contains 74-185mg. Conversely, tea contains an average of 58mg of caffeine and a 400ml cola drink about 45mg [30]. More than 500mg a day of caffeine is considered unhealthy [9], and causes insomnia, nervousness, restlessness, irritability, stomach upset, muscle tremors, and increased blood pressure as well as heart rate.

The human body can synthesize taurine, which is therefore a non-essential amino acid. Amino acids are the building block of protein. Taurine is however semiessential for children as the metabolic pathways that synthesize these amino acids are not fully developed. Taurine is found in the brain, retina, heart, and blood cells called platelets. Taurine constitutes about 0.1% of the total human body weight [14]. Taurine can be found in food like seafood and meat. It helps to regulate level of water and mineral salts, and may improve athletic performance. Taurine has been known to lower blood pressure. Controversial studies state that when taken with caffeine, taurine improves attention and verbal reasoning skills.

There is some indication that taurine taken in quantities greater than 2g per day has some function in the maintenance and possibly in the induction of psoriasis [29], which is a common skin condition that causes redness and irritation. Just one serving of Red Bull contains 1g of taurine [30]. However, the acute toxicity (lethal dose for 50% of 220lb men) is thought to be about 4.4lbs, so a true overdose is unlikely [8].

Glucuronolactone, also known as DGL, is a natural occurring metabolite in the body. It is formed organically from glucose in human liver and controls glycogen production. Glucuronolactone is known to help in clearing toxic metabolites. No known study has been done that evaluates glucuronolactone without caffeine and taurine as variables, but users who supplement with 1-3g per day report positive results in energy and alertness [21]. A serving of Red Bull only contains 600mg [30]. Horne beneficial effects of artificially created glucuronolactone, so it is unsure if the addition has any positive effect on the body. Many energy drinks, including Red Bull, contain vitamin B, the vitamin responsible for the metabolism of carbohydrates, fats, and proteins. Vitamin B12 is particularly important in the formation of blood and the prevention of anemia.

Vitamin B3 contributes to energy production in the human body by converting fats, proteins, carbohydrates and starches, into energy. The supplement form, niacin, is likely safe with most people. One common major side effect is a flushing reaction that causes burning, itching, and redness of the face, arms, and chest; alcohol makes this reaction worse. Other common side effects include: stomach upset, dizziness, and pain in the mouth. Large doses of this vitamin can increase the risk of irregular heartbeat. It also increases blood glucose levels, lowers blood pressure, and worsens allergies [4].

Vitamin B6 is essential to the production of amino acids. Additionally, it is needed for the creation of DNA. Pyridoxine is the most common form of B6 found in energy drinks. As little as 1-6g of this drug a day taken for a year can cause “severe and progressive sensory neuropathy characterized by ataxia (loss of control of bodily movements),” [4]. Other effects found in lower doses of vitamin B6 intake include painful, disfiguring dermatological lesions, photosensitivity, and gastrointestinal symptoms such as nausea and heartburn.

Sugar is one of the most common as well as most dangerous additives on the market today. It’s sweet taste and short-term positive effects lead health experts to consider the possibility of sugar addiction. Natural sugars, such as those found in fruits and dairy products, provide an easily digestible form of good-for-you energy. The synthetic copycats like refined sugar, sucrose, fructose and glucose do far more harm than good.

In fact, more than 32g of extra sugar a day can cause a myriad of health problems [6] such as raised cholesterol levels, suppressed immune system, hyperactivity, anxiety, difficulty concentrating, crankiness, decreased emotional stability, a raised level of neurotransmitters, hypoglycemia, increased blood pressure, interference with protein absorption, and impaired DNA structure [3]. Just one serving of Red Bull contains 27g of sugar [30], and the average cup of coffee contains 32g [34].

Effects of energy drinks when mixed with alcohol:

Mixing energy drinks with alcohol is common practice, prime examples being the “Vodka Red Bull” and banned “Four Loko” drinks. Due to the large number of these drinks consumed, it was relevant to research their effects. Caffeine stimulates the nervous system, while alcohol and taurine are depressants. When “uppers” and “downers” are mixed, there is an increased strain on the body. In rare cases, this can lead to heart failure [3]. There are other,

more common, risks associated with mixing alcohol and energy drinks. A person who has consumed both will be less likely to notice how drunk they are, because they will feel energetic and be less likely to go to sleep when their body's alcohol tolerance limit has been reached. When the body's natural defenses against overconsumption are suppressed, the risk of alcohol poisoning is increased exponentially.

PREVIOUS RESEARCH

To date, there have been a few very frequently cited studies done to evaluate the effects of energy drinks (particularly Red Bull) on physical performance, mental acuity, and feelings of well-being. Most of these studies focus on cycling or driving performance over time.

The paper, *Cycling time trial performance improved by ingestion of a Caffeine energy drink*, described an experiment where cyclists were given 500ml of either a flavored placebo or Red Bull energy drink following a 12 hour fast. 500ml is equivalent to two serving sizes. Average increase in performance was 4.7%, with 83% of the twelve participants experiencing a positive effect [21]. It was noted that blood glucose levels were much higher in the Red Bull group at the beginning of the experiment, but also that the levels decreased quickly. The 12 hour fast may have altered the results because of the necessity of carbohydrates before intensive exercise. There was some doubt raised as to if the increased performance was due purely to the additional energy granted by the sugar in the energy drink. Also, the two serving sizes ingested is double the recommended safe dose, which raises health concerns and does not reflect real-world experience well.

The effect of a taurine-containing drink on performance in 10 endurance-athletes also administered 500ml of Red Bull to cyclists, only not until after 30 minutes of submaximal cycling. This study also administered a version containing only caffeine and used a drink without any 'active' ingredients for the placebo. In the original Red Bull group, heart rate was significantly lower than in the other groups starting 15 minutes after application. Endurance time in the Red Bull group was also significantly longer. The study states "The results of this study show a positive effect of a taurine-containing drink on hormonal responses which leads to higher performance," [17].

The influence of taurine-containing drink on cardiac parameters before and after exercise measured by echocardiography found that in both drinks containing only caffeine and those which contain caffeine as well as taurine increased the peak late diastolic inflow. This means that when the heart relaxed, more blood flowed into the heart faster. However, only energy drinks containing taurine positively affected cardiac contractility, or the ability of the heart to contract regardless of load. The taurine-containing drink also caused a significantly greater stroke volume – the amount of blood pumped out of the left ventricle with every contraction. Increased stroke volume and cardiac contractility is usually associated with a stronger and healthier heart [7]. However, there is concern that artificially creating this condition could be forcing the heart to work harder than it should be.

The study, *Readiness potential in different states of physical activation and after ingestion of taurine and/or caffeine containing drinks* also measured physical performance through self-pedaling. The study found that, while caffeine caused an elevated blood pressure, taurine and caffeine combination drinks did not. "With caffeine bp's increased after lower workload, achieving a level which was reached in placebo trials only after submaximal physical activation... taurine admixture seems to inhibit this effect," [5]. While the reduced pulse rate and blood pressure in taurine-containing drinks can seem like a positive effect, taking 'uppers' and 'downers' together has long been advised against. More research needs to be done on whether or not this is healthy. The lack of experiments, which test performance in activities other than cycling, is also a cause for concern. It is unlikely that such positive effects would be reproduced in an activity such as running, where carbonated drinks are widely recognized as harmful to performance.

The Effects of Red Bull Energy Drink on Human Performance and Mood found improved aerobic endurance as well as anaerobic performance (maximum speed) were measured during endurance cycling after ingesting Red Bull. Reaction time, concentration, and memory (immediate recall) were also positively influenced, which reflected better subjective alertness. The paper notes these widespread positive effects as a result of the combination of caffeine, taurine, and glucuronolactone [36].

A taurine-and caffeine-containing drink stimulates cognitive performance and well-being measured the effects of a drink that contained caffeine, taurine, and glucuronolactone vs. a placebo. At the end of the 60-minute experiment, latency (time between stimulus and beginning of response) and motor reaction time were significantly longer in the

placebo group but unchanged in the energy drink group. Feelings of well being were also decreased in the placebo group but not in the energy drink group. Because half of the participants were non-caffeine users, the positive effect on well being cannot be described as a return to normal after caffeine withdrawal [33].

Positive effects of Red Bull Energy Drink on driving performance during prolonged driving examined the effects of 250ml (one serving size) of Red Bull on participants during a 6-hour drive. Unlike other experiments, the test subjects were not required to be fatigued prior to the start of the driving experiment, which means that a prevention of exhaustion as opposed to a reversal of exhaustion was tested. After 2 hours of highway driving, the non-placebo group was given a 15 minute break during which they drank a Red Bull. During the 3rd and 4th hour of the test after consumption, Red Bull had a significant impact on driving as well as subjective sleepiness. However, no significant differences were observed during the first two hours after consumption [25]. This response is curious, as usually Red Bull is expected to have the greatest effect in the first few hours after consumption.

Beneficial effects of an “energy drink” given to sleepy drivers more closely represented the expected results. 500ml of a glucose-based energy drink were given to 11 sleepy participants. “Energy drink significantly improved both lane drifting and reaction time particularly for the first hour,” [19].

Efficacy of a ‘functional energy drink’ in counteracting driver sleepiness also revealed a greater effect towards the beginning of the drive. After 5 hours of sleep, participants were given an energy drink that contained sucrose, glucose, 80mg caffeine, taurine, glucuronolactone, and vitamins. The participants were then asked to drive between 14:00 and 17:00 hours. The energy drink group exhibited significantly reduced sleep-related driving incidents and subjective sleepiness for the first 90 minutes of the drive, and an EEG reflected less sleepiness during this period. None of these driving experiments tested for a difference between the common energy drink blends and a caffeine-only drink [32]. Caffeine reduce sleepiness, but there is no known experiment to evaluate whether or not taurine and glucuronolactone affects sleepiness.

In summary, the above-mentioned studies concluded some positive effects of energy drinks and some limitations of these studies were pointed out.

EXPERIMENT

Our research group conducted an experiment to compare the marketing claims of Red Bull and coffee to real-world results. To do this we created three groups consisting of ten people who drank Red Bull, eight who drank Starbucks Frappuccino, and a control group who did not drink anything consisting of two people. To conduct this experiment we relied on participants who donated their time. The two control group members were part of the research team, and the third member of the research team drank coffee.

In this experiment we tested for three variables; heart rate, SpO₂%, and reaction time. Saturation of peripheral oxygen (SpO₂%) is the oxygen saturation level usually measured with a pulse oximeter. It can be calculated with the pulse oximetry as the percentage of oxygenated hemoglobin.

During the reaction time test, we had each participant record their reaction time to a change in color three times, and averaged those values. We had each participant drink their designated drink within the first ten minutes, and performed each test every ten minutes for an hour.

From the data we collected we produced the following graphs (Figs. 1-3). The data plotted on the graphs was produced by plotting the average of the values, minus the min and the max of each data set. This was done to produce a more accurate graph, which was not tainted by statistical outliers. In these graphs Series1 represents Red Bull, Series2 represents coffee, and Series3 represents the control.

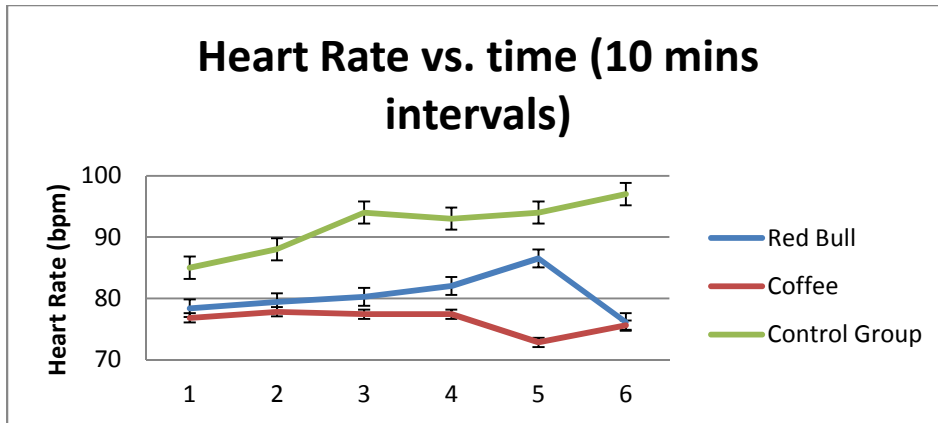


Fig. 1

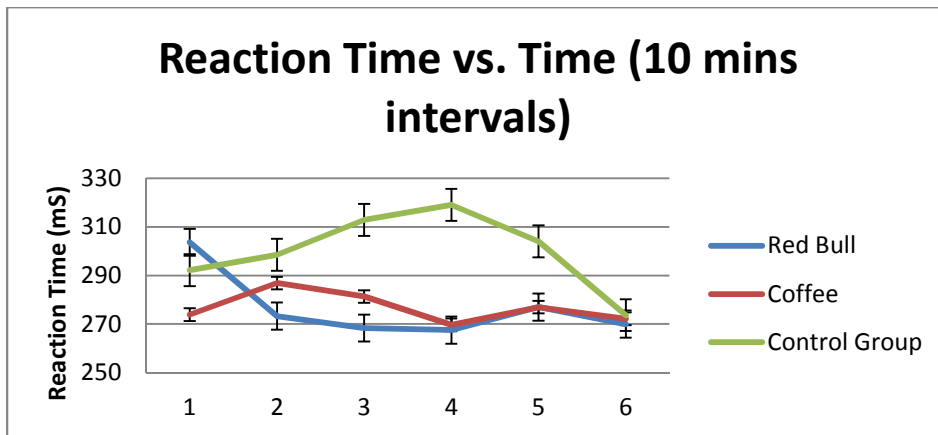


Fig. 2

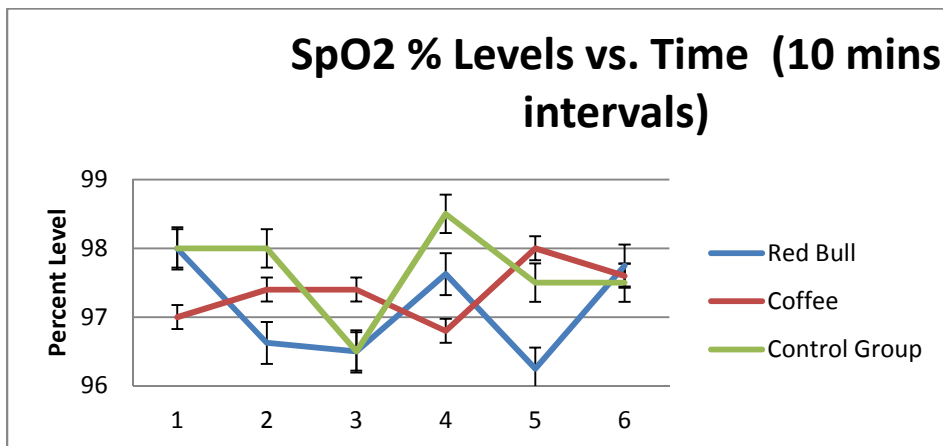


Fig. 3

DISCUSSION

After analyzing this data we came to several conclusions. We found that the control group's heart rate rose the most through the hour. This data could be unreliable because there were only two members in this group. The Red Bull group's heart rate rose slightly, and the coffee group's heart rate fell throughout the hour. Red Bull contains many ingredients, one of which is taurine. This ingredient lowers heart rate and blood pressure. However it contains stimulants such as caffeine that raises your heart rate. Coffee also contains stimulants such as caffeine. However, in our experiment the heart rate of the coffee drinkers went down. There was not a big enough difference to positively distinguish that one of the two drinks effects heart rate more than the other.

All of the group's reaction times improved throughout the experiment. This was expected because the participants will become more comfortable and used to taking the test throughout the experiment. Both the control group and the coffee drinkers had similar improvements over the hour they were tested. However, on average, the Red Bull drinkers performed much better on the reaction time test. As the hour progressed, they continued to have better reaction times. After 40 minutes the difference between the reaction time values of the Red Bull Group and the coffee group became less significant.

The blood oxygen saturation levels did not vary a significant amount throughout the hour for any of the groups. These levels show how fast the subjects' metabolism rate is because if metabolic rate increases the levels of oxygen in blood also increases. Since there was no increase in blood oxygen saturation level in our subjects, we can conclude that neither coffee nor Red Bull significantly affect metabolic rate.

Based on the results of our experiment, we concluded that Red Bull affects people more than coffee does. Red Bull raised heart rate and improved subjects' reaction time more than coffee did. Our results also showed that both drinks lowered heart rate more than having no drink at all. Even though we found Red Bull to be more effective than coffee, this doesn't take into account the issue of how healthy each drink is.

The Healthiest Choice:

While no energy drink can be called healthy, none have been proven immediately harmful to health when taken responsibly. The most important consideration to take into account is the cumulative and synergetic effects of the multitude of chemicals found in the most common energy drinks, as well as the effects of higher-than-recommended dosages of B vitamins and amino acids.

While the caffeine, taurine, or sugar found in a single serving of a drink alone might not have any large effect on day-to-day health, in combination they are best used sparingly. Just like any other sweet treat, energy drinks won't help with weight loss or overall health goals. In addition, it is important to remember that it is easy to build up a tolerance to caffeine and taurine. When this tolerance occurs, it is tempting to consume more of these drugs in order to enjoy the positive side effects. However, the body does not build up the same kind of tolerance to the negative effects of these drugs. In general, it is important to stick to less than 500mg of caffeine, 2g of taurine [39], 1g vitamin B6 [4], and approximately 32g of sugar per day [35] if negative side effects are to be avoided. Often, these dangerously high quantities can be found in one large can of Red Bull or 3-4 8oz servings of coffee.

No energy drink is necessarily healthier than the other, and the best choice often depends on the individual. Red Bull and Coffee contain roughly the same amount of sugar and caffeine. Red Bull can be considered less healthy due to the additional ingredients, although, to a degree, taurine and B-vitamins are essential to good health and glucuronolactone helps to clear toxic metabolites and improves liver function. The best option is to get enough sleep, drink filtered coffee rather than espresso or Red Bull, and to use more regulated supplemental vitamins under the care of a physician when necessary.

In general, it is best to look for a drink that contains the lowest amount of caffeine and sugar while still accomplishing the needed results, and to avoid consuming energy drinks unless absolutely necessary. Before trying a new energy drink, it is important to research the contents to find out about the drug interactions and other health risks. As with every product, it is best to read into any marketing claim, especially those that advertise a 'healthier' alternative.

Alternatives:

5-Hour Energy is a shot-sized energy drink that was introduced in 2004. It was designed to be a healthier and more portable alternative to popular energy drinks like Red Bull and coffee. The shots are loaded with B-vitamins,

including 8333% of the recommended daily value of B12, as well as amino acids, which are essential to the creation of protein and therefore to nearly every bodily function. 5-Hour energy, a common energy supplement, contains as much as 40mg of vitamin B6, or 2000% of the recommended daily value [1]. Each serving is sugar free, contains no herbal stimulants, and has only four calories. The energy shots come in a variety of caffeine concentrations. The original 5-hour energy contains about as much caffeine as a cup of coffee, or about 130mg. The “Decaf” version contains 6mg of caffeine - as much as a half-cup of decaffeinated coffee, while the extra strength version contains as much caffeine as 12 ounces of coffee.

5-Hour Energy’s target energy is working adults who don’t have time to make or buy coffee. Their major selling point is the lack of crash that usually comes after consumption of other energy drinks. However, the fine print clarifies that no crash means no crash from sugar [1], which means that the caffeine found in the drink will likely still cause a withdrawal crash. Other than the lack of sugar, the ingredients in 5-Hour energy are similar to Red Bull, and both use taurine and caffeine as the main energy supplements. Additionally, 5-Hour energy contains many added ingredients that are marketed as healthy supplements and are not found in Red Bull - at least not in such large quantities. However, some of the added ingredients have serious side effects in large quantities. With some of the ingredients already being found in quantities greater than 83 times the recommended daily value in one serving of 5-Hour Energy, these harmful doses are easy to attain accidentally [14] [15].

Recommendations:

If we were given more time to research, we would have delved deeper into several topics. Foremost, we would have spent more time researching the effects of caffeine, taurine, and glucuronolactone when in combination. We also would have researched the effects of Red Bull and coffee in combination with alcohol more closely. Additional attention would also be paid to energy-drink-related death, and the effects of these drinks on the heart, especially when more than recommended amounts are ingested. If we were to conduct further experiments on the effects of Red Bull and coffee, we would make several changes from our base experiment. The first thing we would do would be to include more test subjects. We did our best to evenly disperse our subjects through the groups, male and female; this would have been easier to do with more people. We also would have assigned more people to the control group. We found it hard to control the environment within the experiment due to our limited resources. We had every subject in the same room, but we found that each person was doing different activities. Some were doing homework, and others were having conversations. These different factors could have an effect on the participant’s heart rate, and throw off our results. We also found that with only one pulse oximeter we could not take measurements of heart rate and SpO₂ levels very quickly. This caused each participant’s data to be taken at a different time, adding to the uncertainty of the results.

CONCLUSION

After performing extensive research and conducting our own experiment on the effectiveness and health effects of energy drinks, we can conclude that energy drinks have the effects they are advertised to for most people. Our methodology was as follows: Our motivation was to investigate potential negative effects of energy drinks, because of their popularity. First, we researched the current state of knowledge by reading many papers reporting on studies on energy drinks, and the claims made by manufacturers of the drinks. We developed an experimental procedure to better quantify possible effects of the popular Red Bull energy drinks and caffeine on blood oxygen level and devised a test to quantify the effects on reaction time. The purpose was to compare their effects. Based on our quantitative results, we conclude that it has become apparent that the consumption of these energy drinks will likely not seriously harm you. This conclusion agrees with many past studies we researched. However, we believe they are not healthy to drink on a regular basis. Many of the ingredients found in popular energy drinks have a laundry list of side effects and contain more than the recommended amount of potentially harmful chemicals. While the side effects of each ingredient are not serious enough to be banned by the FDA, the effects of these drugs in combination have not been evaluated. When drugs designed to boost energy such as caffeine are mixed with drugs designed to keep the heart rate from rising such as taurine, the body is put under a tremendous strain. Coffee could be considered safer because it contains only uppers, but these ingredients will raise heart rate, an unhealthy side effect. While these drinks may not cause immediate health problems, they will increase the risk of or exacerbate serious conditions in the future.

The above study may be continued and further improved by increasing the sample sizes especially of the control group which in our study was minimal. Another way to improve this study in the future is to have a medical doctor on-board to monitor other health parameters that may be potentially affected by energy drinks.

The above project is an example of a quality interdisciplinary undergraduate research. Its uniqueness is that it is exploratory [40] in nature and interdisciplinary in approach and makes use of minimal resources within the budget of typical undergraduate colleges, while it involves a thorough and rigorous exposure to all facets of research. This research was performed in the highly interdisciplinary environment of an electromechanical engineering program with a biomedical systems engineering concentration [41]. This approach is compatible with the conclusions of the 2005 report by the National Academy of Engineering [42] entitled *The Engineer of 2020: Visions of Engineering in the New Century*, which recommends the following: "Colleges and universities should endorse undergraduate research as a valued and rewarded activity for engineering and should develop new standards for faculty qualifications.....Engineering educators should introduce interdisciplinary learning in the undergraduate curriculum."

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