Exploring the Effects of Caffeine and Glucose on Cognitive Performance

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Abstract

The effects of caffeine and glucose on cognitive performance were investigated using a short-term memory test, reaction speed test, and the Stroop test. Early morning online test sessions were performed on 15 subjects (8 females, 7 males), 30 minutes after beverage consumption. Following an overnight fast, each subject consumed a total of 7 different beverages and completed 7 test sessions separated by at least 24 hours. Each session was conducted on a computer in a controlled environment. Although each participant signed a consent form, subjects were not alerted to the specific beverage before consumption. The collected data fails to suggest any statistically significant improvement in cognitive performance after consumption of caffeine and glucose.

Introduction

Mental fatigue is a major concern in the modern world. Many individuals rely on highly caffeinated and highly glycemic beverages to enhance their levels of alertness when they feel tired (Rao, 2005). Energy drinks such as Red Bull claim to "vitalize body and mind" by "increasing performance, concentration and reaction speed, and improving vigilance" (Red Bull USA). Among the ingredients of Red Bull are caffeine and glucose, which are individually known to increase the cognitive functions of reaction speed, memory, and vigilance (Scholey, 2004).

The brain is the most metabolically active organ in the human body (Kennedy, 2000). It requires a large amount of glucose as its primary energy stores. These requirements are met almost entirely by the oxidative breakdown of blood-borne glucose (Weiss, 1986). Therefore, fluctuation in the availability of glucose will provide a difference in the metabolic function of the brain.

Previous research has consistently found enhancement of memory after the ingestion of glucose containing beverages (Meilke, 2005). Nevertheless, the precise task demands, conditions and amount of glucose needed to enhance cognitive function are still under investigation (Meilke, 2005).

Caffeine (1,3,7-trimethylxanthine) is a plant alkaloid that physiologically acts to increase the excitability of the adenosine-sensitive sympathetic nervous system (Glade, 2010). Several hypotheses have been investigated for the biochemical mechanism of caffeine at the cellular level. Three predominate mechanisms of action have been described, including: intracellular mobilization of calcium, inhibition of phosphodiesterases, and antagonism at the level of the adenosine receptor (Nehlig, 1992). A primary role of adenosine in the central nervous system appears to be the inhibition of the release of various neurotransmitters, including: acetylcholine, serotonin, norepinephrine, dopamine, gamma-aminobutyric acid (GABA), and glutamate (Nehlig, 1992). Additionally, as a competitive antagonist, caffeine inhibits the enzymatic degradation of cyclic adenosine monophosphate within the postsynaptic cell. Therefore, caffeine may increase the strength of the transmitted signals (Spraul, 1993).

By increasing sympathetic nerve activity, caffeine stimulates fat lipolysis. Theoretically, caffeine ingestion increases fatty acid oxidation—leading to an increase in energy and blood-borne glucose levels (Glade, 2010). In addition to caffeine's effects on energy levels, it also increases serotonin concentrations in brainstem regions that cause excitation of skeletal muscle motor units. The neurons of the raphe nuclei are the principal source of serotonin release in the brain (Rao, 2005). Axons from the neurons of the raphe nuclei form a neurotransmitter system, reaching almost every part of the central nervous system (Rao, 2005). Therefore, many studies have shown that caffeine postpones fatigue and increases endurance (Glade, 2010).

In previous studies, the effects of epinephrine (caffeine intensifies the effects of epinephrine) and glucose have given mixed results depending on dosage (Wade, 1995). It is thought that epinephrine and glucose have similar inverted U-shaped dose response curves. This implies an optimum dose for memory enhancement. Lower and higher end doses of epinephrine or glucose gradually impair the subjects' ability to retain information (Wade, 1995).

Our research examined these two ingredients, glucose and caffeine, combined and examined their effects on cognitive performance. This was achieved by administering tests to analyze reaction speed, short-term memory, and selective attention after ingesting beverages containing glucose and/or caffeine. If the effect on cognitive function is greater after ingestion of these substances, is it an additive, partially additive, or synergistic result.

Methods

Fifteen adults (8 females, 7 males) between the ages of 20 and 22 (mean age=21.4) participated in this study. There were no exclusionary criteria for this study; however, all participants were required to sign an informed consent stating that they knowingly consumed beverages with varying levels of glucose, caffeine, taurine, and other ingredients (Appendix 1 and Table 1). All participants were recruited for the study by the investigators and received no compensation for their involvement.

Short Term Memory Test

The effects of caffeine and glucose on memory were assessed using an online test. The short-term memory test displayed a series of numbers for ten seconds at a time and measured the amount of numbers recalled. (http://www.braingle.com/mind/test_numbers.php)

Response Speed Test

This online test evaluated the effects of the beverages on the participants' reaction speed. The test consisted of a colored block in the middle of the screen, which turned a different color after a random amount of time, at which point the participant clicked the colored block and reaction speed was recorded. (http://humanbenchmark.com/tests/reactiontime/index.php)

The Stroop Test (Golden, 1978)

Selective attention was assessed by the Stroop test. This test, which was administered online, was a timed test that involved reading out loud off of lists of colored words. (http://faculty.washington.edu/chudler/words.html#seffect)

Procedure

Participants, who were recruited by the investigators in the home and school setting, were asked to volunteer their time on seven separate mornings. The drinks that were administered amongst the participants were randomly chosen each morning. When choosing the doses of each beverage, it was important to keep either the amount of sugar or amount of caffeine constant. With Red Bull as the model beverage, doses of other beverages were determined by trying to match the amount of caffeine and sugar to Red Bull. For Mountain Dew, it was impossible to match the amount of caffeine in Red Bull without an exceedingly high amount of sugar and vice-versa, so a value was chosen to try and balance this discrepancy. All of the beverages without caffeine had sugar amounts that exactly matched the amount in Red Bull. Coffee and Diet Mountain Dew, which lack sugar, were given doses that mirrored the amounts of caffeine in Red Bull and Mountain Dew, respectively. Throughout the experiment, each participant eventually consumed all of the beverages listed in Table 1.

Table 1: Beverages Administered			
Beverage	**Amount of beverage (ounces)**	**Amount of caffeine (mg)**	**Amount of sugar (g)**
Red Bull	8.3	80	27
Mountain Dew (positive control)	7.0	55	47
Water (negative control)	8.3	0	0
Beverage	**Amount of beverage (ounces)**	**Amount of caffeine (mg)**	**Amount of sugar (g)**
Starbucks Regular Brewed coffee	4	90	0
Diet Mountain Dew (positive control)	7	55	0
Water	8.3	0	0
Beverage	**Amount of beverage (ounces)**	**Amount of caffeine (mg)**	**Amount of sugar (g)**
Hawaiian Fruit Punch	10	0	27
Sprite (positive control)	8	0	27
Water (negative control)	8.3	0	0

After volunteers signed an informed consent document stating that they understood the amounts of caffeine and glucose they could potentially drink at any point in the study, they were randomly assigned an order in which they would consume the beverages. There were three different orders, each of which contained a positive control, a negative control and the beverage being tested. The positive control varied for each beverage being tested, but was assigned to produce the same or similar results as the beverage. The negative control, which was water for all of the orders, was designed to act as a null hypothesis, thereby having essentially no effect on the participants.

Each volunteer completed a baseline before beverage consumption so they could associate themselves with the online tests and to see if they had any questions regarding the tasks. After establishing a baseline, volunteers were asked to drink their assigned beverage for that day when they woke up, so that there were not competing substances from their normal diet that would affect the results. Participants would drink their assigned beverage and would begin the online tests 30 minutes post-consumption. Participants were not informed which beverage they would be receiving before each test. Beverage intake was spaced out at least 24 hours to allow caffeine and/or glucose to allow time to be metabolized.

The tasks were given in random order. For the memory test, participants were taken to a website where they were shown a series of numbers for ten seconds, after which the numbers disappeared off the screen and the participants were prompted to type in the series of numbers as they remembered. The series of numbers continued to increase by increments of one until a participant could no longer recall the correct order. The last amount of numbers that was recalled correctly was recorded and the test was administered once per beverage. For the response speed test, volunteers used a computer mouse to click a block on the computer screen as soon as the block changed colors. Participants were asked to complete the response speed task ten times in succession, with the average response speed being recorded at the end of the task. The Stroop test was administered by giving participants a list of colored words online and asking them to say out loud the correct color of the text, rather than the word that was written. In the first round, the color of the text matched the written word (ie. the word blue is written in blue text). In the second round, the color of the text is different than the word that is written. The Stroop test, in its two round entirety, was administered twice per round of beverage consumption, with the average time being recorded.

At the completion of the 7 different days of testing, participants were debriefed and thanked for their participation.

For data analysis a paired one-tailed distribution t-test on Excel was used to determine if there was a statistically significant difference between the means of the data sets being compared. T-tests were performed for the positive and negative controls, and for Red Bull in comparison to only caffeine and to only glucose. The null hypothesis for all comparisons was that the two means were not significantly different while the alternative hypothesis was that the two means were significantly different. If the p-value was below .05 the null hypothesis was rejected. The glucose drink (Hawaiian Fruit Punch) was compared with both its positive and negative control to determine if there were other potential factors contributing to the variables tested. Also, the caffeine drink was analyzed in this manner with its positive and negative controls. If the controls were suitable for the particular drink, it was expected that for the positive control the null hypothesis would not be rejected while for the negative control the null hypothesis would be rejected. Then, a t-test was performed on the mean of the Red Bull variables in comparison with the coffee and Hawaiian Fruit Punch to determine which, if any, of the variables were shown to have a statistically significant difference in the means.

Results

Hawaiian Fruit Punch: Glucose-only drink

The mean reaction speed for Hawaiian Fruit Punch (HP) was slower than that of the positive control, Sprite, but faster than that of the negative control, water. The mean amount of numbers recalled in the memory test for HP was lower than both Sprite and water. The mean time required to complete the Stroop test was higher for water and lower for Sprite in comparison to HP. In all categories, the p-values indicate that there is no statistically significant difference between the means of the variables measured for HP and either the positive or negative control. It was expected that there would be no statistically significant difference between the positive control and HP, but for the negative control a statistically significant difference between the means was expected. Given these results, it is unclear whether the positive and negative controls were appropriately chosen, or it is possible that glucose does not significantly influence the factors measured. Results for the glucose containing beverages can be seen in Table 2.

Table 2: Glucose			
Rxn Speed (msec)	**HP**	**Sprite (PC)**	**Water (NC)**
Average	272.79	271.29	273.18
p-value		0.3645	0.4885
Memory			
Average	8.4	8.73	8.73
p-value		0.1671	0.227
Stroop (sec)			
Average	14.85	14.17	16.32
p-value		0.1939	0.1712

Coffee: Caffeine-only drink

The mean reaction speed of coffee was faster than that of both the positive control, Diet Mountain Dew, and the negative control, water (Table 2: Caffeine). The mean amount of numbers recalled for the positive control was lower than that of coffee, while that of the negative control was higher than that of coffee. The mean time required to complete the Stroop test was lower for the positive control and higher for the negative control in comparison to the coffee. Similar to the glucose results, the p-values indicate no statistically significant difference among the means of any of the variables for both the positive and negative control compared with coffee. Results for the caffeine containing beverages can be seen in Table 3.

Table 3: Caffeine			
Rxn Speed (msec)	**Coffee**	**Dt MD (PC)**	**Water (NC)**
Average	269.63	273.39	273.18
p-value		0.1941	0.399
Memory			
Average	8.67	8.33	8.73
p-value		0.1035	0.4461
Stroop (sec)			
Average	14.38	14.16	16.32
p-value		0.2579	0.1379

Red Bull: caffeine and glucose

Like the previous results of caffeine-only and glucose-only**,** the positive and negative control measurements for Red Bull show no significant difference between the means (Table 4). By only considering the means, the reaction speed of Red Bull was faster than that of both Mountain Dew and water. The mean amount of numbers recalled for the positive control was less than that of Red Bull, while the negative control was greater than that of Red Bull. The mean time required to complete the Stroop test was lower for the positive control and higher for the negative control in comparison to Red Bull. Results for the caffeine and glucose containing beverages can be found in Table 4.

Table 4: Caffeine and Glucose			
Rxn Speed (msec)	**Red Bull**	**MD (PC)**	**Water (NC)**
Average	271.21	272.29	273.18
p-value		0.3216	0.4418
Memory			
Average	8.67	8.4	8.73
p-value		0.1818	0.4471
Stroop (sec)			
Average	14.57	14.18	16.32
p-value		0.1709	0.167

Red Bull in comparison to only-glucose and only-caffeine

In comparing the mean data of Red Bull and coffee, the reaction speed is faster for coffee, the amount of numbers recalled is the same, and the time required to complete the Stroop test is higher for Red Bull (Table 5). The p-values indicated no significant difference between the means of the variables measured for Red Bull and coffee.

In comparing the mean values of Red Bull and HP, the reaction speed is faster for Red Bull, the amount of numbers recalled was greater for Red Bull, and the time required to complete the Stroop test was less for Red Bull (Table 5). Again, the p-values indicate no significant difference between the two sets of data for any of the variables measured.

Table 5: Red Bull v Coffee and Red Bull v HP			
	Red Bull	**Coffee**	**HP**
Rxn Speed (msec)	**(caffeine and glucose)**	**(caffeine only)**	**(glucose only)**
Average	271.21	269.63	272.79
p-value		0.3792	0.3794
Memory			
Average	8.67	8.67	8.4
p-value		0.5	0.2947
Stroop (sec)			
Average	14.57	14.38	14.85
p-value		0.3605	0.3337

Discussion

The mean of the data sets were compared using a t-test to determine if the difference of the means of the three variables tested (reaction speed, memory, selective attention) was statistically significant. T-tests were performed for the positive and negative controls, and for Red Bull when compared with only caffeine and only glucose.

Our data failed to show statistically significant data to suggest that caffeine and glucose improved cognitive function. Although our experimental design is easily reproducible, there are a few aspects of our plan that should be adjusted for future research.

Due to limited resources and time, the subjects that were picked for this study were not picked randomly. Therefore, these subjects are roommates and friends. As these cognitive tests report a score afterwards, researchers found that the various subjects made the tests a competition. Because these tests were repetitive, the subjects improved their scores. Was this a result of our measured variable? Or was this the result of competitive nature and repetition?

A second issue that has been noted is the variable caffeine tolerances amongst subjects. Some subjects are regular caffeine drinkers; others are not. It is hypothesized that the amount of tolerance one has for caffeine changes the playing field and the variable being measured. As mentioned in previous studies, caffeine and glucose have U-shaped dosage response curves of about 100mg/kg. However, this dosage is easily shifted depending on the tolerance of the subject (Wade, 1995). Future research would include screening of subjects for caffeine tolerance. Ideally, subjects would be administered caffeine doses dependent on their average daily caffeine intake. This would be done from calculations done in previous studies (Wade, 1995).

A third potential problem that we see with our project is the difficulty of cognitive demand. Our study contains a memory test, a reaction speed test, and a selective attention test. Previous studies observed improvements in performance that were dependent on the cognitive difficulty of the test (Mielke, 2005). Yet, other studies suggested that further task difficulty manipulations be performed to analyze the magnitude of glucose and caffeine enhancement (Mielke, 2005).

The amount of sleep that each subject received prior to testing is another variable that was not possible to control. All tests were administered in the morning; therefore, it is hypothesized that the amount of hours each subject received greatly influenced their testing.

There are other ingredients in Red Bull such as Taurine, glucoronolactone, and B-group vitamins, that could potentially impact the results obtained, and they were not specifically tested for in this experiment. The amino acid taurine is a common ingredient in many energy drinks, so the effects of this specific ingredient were researched. Although it has been found that taurine is required in neuronal function, especially during maturation, the mechanisms of taurine required for optimal nervous system function are still unknown (Pasantes-Morales, 2010).

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Appendix 1. Consent Form

Consent Form

The experiment being performed is aimed to measure differences in cognitive function after consuming beverages containing glucose and/or caffeine. These are all legal beverages, sold in the United States and regularly consumed by many individuals. Following is a list of all ingredients, separated by beverage.

1) **Carbonated water, high fructose corn syrup, concentrated orange juice, citric acid, natural flavors, sodium benzoate (preserves freshness), caffeine, sodium citrate, erythorbic acid (preserves freshness), gum arabic, calcium disodium edta (to protect flavor), brominated vegetable oil, yellow 5**
2) Carbonated water, concentrated orange juice, citric acid, natural flavors, citrus pectin, potassium benzoate (preserves freshness), aspartame, potassium citrate, caffeine, sodium citrate, acesulfame potassium, sucralose, gum arabic, sodium benzoate (preserves freshness), calcium disodium edta (to protect flavor), brominated vegetable oil, yellow 5
3) Carbonated water, sugar, citric acid, acidity regulator (E331), flavourings, preservative (E211)
4) Taurine, GLUCURONOLACTONE, caffeine, b-group vitamins, sucrose, glucose
5) Caffeine, Tannin, Thiamin, Xanthine, Spermidine, Citric Acid, Cholorogenic Acid, Trigonelline, Acetaldehyde, Spermine, Hypoxanthine, Putrescine, Scopoletin
6) Water, high fructose corn syrup, and 2% or less of each of the following: concentrated juices (pineapple, orange, passionfruit, apple), purees (apricot, papaya, guava), citric acid, natural and artificial flavors, pectin, gum acacia, gum ghatti, glycerol ester of wood rosin, sodium hexametaphosphate, red #40, blue #1, sodium benzoate and potassium sorbate (preservatives), and ascorbic acid (vitamin C)

Following consummation of beverages, online tests will be performed that include you having to click or type in letters or words. If at any time you feel uncomfortable, you can discontinue participation in the experiment.

By signing below, you consent to being a participant in the experiment

Signature   Date

____   __________