Assessing the Synergistic Effect of Caffeine and Sugar on Cognitive Performance in Undergraduate Students

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Working independently, both caffeine and sugar provide benefits to attention and memory. However, there is sparse literature on the synergistic effects on improved cognitive performance between caffeine and sugar when taken together. This study explored the dynamics between caffeine and sugar when consumed underordinary conditions – as a cup of coffee. Twenty-four undergraduate students (15 women and 9 men) were asked to complete a baseline cognitive test, and one of the three variables was given at random in the form of a cup of coffee: decaffeinated with sugar, caffeinated with no sugar, and caffeinated with sugar. The remaining two variables were administered at random over the next two sessions. Results were compared within subjects and between subjects to assess effects on short-term memory and cognitive performance. We hypothesized that there would be a significant improvement on short-term memory as measured by correct responses on nback tests when caffeine and sugar were consumed simultaneously, as opposed to consuming the caffeine or sugar independently. Additionally, we anticipated that participants' caffeine consumption habits would influence the effects of different treatments on cognitive performance. The results did not show a synergistic effect on cognitive performance by caffeine and sugar when taken together, although there was a trend supporting this hypothesis in non-regular coffee drinkers as opposed to habitual coffee drinkers. Additionally, there was evidence supporting our hypothesis that caffeine habits influence the cognitive benefits of caffeine and sugar consumption. Non-coffee drinkers saw a higher increase in cognitive performance after consuming caffeinated beverages with sugar, while coffee drinkers received greater benefits from drinking caffeinated beverages without sugar.

Introduction

Caffeinated drinks are second only to water as the most frequently consumed beverages world-wide (Quinlan 1997). About 86% of the world's population regularly consumes some form of caffeine, such as tea, coffee, soda, and energy drinks (Scholey and Kennedy 2004). Caffeine has a double-ringed molecular structure similar to that of adenosine, making it a competitive antagonist to adenosine. As the day progresses, adenosine binds to its receptors in the brain, modulating neuronal activation and causing drowsiness. However, when caffeine binds to adenosine receptors, it blocks the binding of adenosine, maintaining a state of vigilance (Ferreira et al. 2014). The beneficial effect of caffeine on attention, memory, and mood are also well-documented (Koppelstaetter et al. 2008). It is worth mentioning, however, that these studies were conducted using caffeine pills, taken simply with water. Therefore, the question becomes – is there an effect in consuming caffeine in its common vehicle, coffee, where temperature, smell, and other factors play such pivotal roles?

Many people tend to consume much of their caffeine with sugar, which is then broken down by the body into its two components, glucose and fructose. This is particularly relevant because most neurons and glia constitutively express glucose receptors, as it is the primary source of energy in the brain (Scholey and Kennedy 2004). Studies have been conducted on the effects of glucose on verbal long-term retrieval, facilitation of cognitive executive performance, and an increase in declarative memory performance (Serra-Grabulosa et al. 2010).

Interestingly, not much research exists on the combined cognitive effects of these two agents. However, a growing body of literature supports the hypothesis that there may be a synergistic effect on cognitive performance between caffeine and glucose. In one such study, energy drinks containing glucose, caffeine, and herbal flavoring were given to participants in either "whole drink" form, or in fractions of the component parts. The results showed that not only did the whole drink yield a greater benefit to cognitive performance – but results of the isolated fractions could not predict the benefits of the caffeine and glucose when taken together, suggesting a synergy between the two (Scholey and Kennedy 2004). In two sequential studies, Adan and Serra-Grabulosa (2010) observed the synergistic effects of caffeine and glucose on attention, manual dexterity, and immediate-, consolidation-, and working-memory tasks. In the second study, Serra-Grabulosa et al. (2010) followed up their first study by using functional magnetic resonance imaging (fMRI) to locate and quantify neuronal activation during sustained attention tasks when patients were given glucose, caffeine, or glucose/caffeine beverages. They found that scores in cognitive performance tasks for those participants who had taken both caffeine and glucose were correlated to lower neuronal activation when compared to scores from participants who had only taken caffeine or glucose alone. Based on such results, if caffeine's effects are directed through the brain's adenosine pathways, and sugar's effects operate primarily within the glucose pathways, we predicted that these two agents might work together synergistically to improve cognitive function.

The aim of this study was to measure the dynamics between caffeine and sugar, in a natural vehicle, coffee, and their effects on cognitive performance by comparing the participants' baseline scores to each of their trial scores and assessing any changes. This study will contribute to the growing body of evidence which suggests that a synergistic effect on cognitive performance exists between caffeine and sugar. Furthermore, it sheds light on the

influence of these two agents when consumed in caffeinated beverages versus caffeine pills. The hypothesis was that drinking caffeine and sugar together, as a cup of coffee, would improve cognitive performance more than either caffeine or sugar could independently.

Methods

This study was a within-subjects and between-subjects design, and included 24 volunteer participants (15 women and 9 men) who were undergraduate students at the University of South Carolina, Aiken. Each participant was screened for use of prescription medication and for excessive use of caffeine (more than three servings of coffee or other caffeinated drinks per day) or nicotine products (more than two cigarettes or the equivalent nicotine products per day) prior to selection for the study. Participants were required to abstain from stimulants such as coffee, tea, soda, and chocolate for at least 12 hours prior to their cognitive tests. Additionally, participants were asked to fast for at least 4 hours prior to tests to allow for any caffeine and/or sugar to be digested quickly and efficiently. Attempts were made to maintain the same time schedule throughout the three testing sessions in order to mitigate confounding factors – participants were asked to complete all three sessions in the morning, or all three in the afternoon. Prior to any testing, a signed informed consent statement was gathered from each participant outlining all rights of the participant, as well as details of the study, to include description of the procedure, expected time frames, potential risks to the participant, and a confidentiality agreement.

In the first session, each participant completed a baseline cognitive performance test prior to ingesting any caffeine or sugar. This preliminary test served as the control arm of the study. After the baseline was obtained, a randomization program was used to choose which of three tests would be conducted during that session: (1) one cup (250 ml) of normally caffeinated coffee (~125 mg caffeine) with 15 g of sugar, (2) one cup of decaffeinated coffee with 15 g of sugar, or (3) one cup of normally caffeinated coffee with no sugar. The second and third tests were randomly assigned over the next two sessions. Although the participants were likely aware of which combination of caffeine and sugar they were drinking, this knowledge is unlikely to have affected their cognitive performance during testing sessions.

The cognitive performance task began about 20 minutes after each participant drank the coffee, allowing enough time for digestion of sugar and stimulation by the caffeine (Liguori et al. 1997). The n-back task is a well-established test of working memory and cognitive performance. It consists of 1-back, 2-back, and 3-back tests, which assess short-term memory and focus. After each session, n-back results were compared to baseline results using Statistical Package for Social Sciences (SPSS) analytic software. These results, in turn, were correlated within each participants' scores to assess the effect of each treatment on short-term memory and cognitive performance. Scores were ultimately compared within and between subjects according to treatments and habits.

Results and Conclusions

There was no difference between treatment groups for the 1-back scores (Fig. 1). This could be due to the 1-back task being a low cognitive load task which most people score well on, which leaves little room for improvement. A repeated-measures ANOVA showed a significant difference between scores within subjects across treatments ($p=0.008$) in the 2-back task, suggesting that caffeine and/ or sugar did provide a cognitive advantage to the participants. Specifically, there was improvement between the baseline and caffeine-only treatment ($p=0.023$), and between the baseline and caffeine/sugar treatment ($p=0.018$) in the 2-back task. However, there was no significant difference between these two treatments. There was also no improvement for the sugar alone group. In the 3-back task, there was improvement between the baseline and caffeine-only treatment, but no improvement for any of the other treatments. The significant variation in the 3-back scores, as shown by the error bars, may reflect the fact that this task is more difficult, leading to greater variation in scores between participants. It also suggests that a participant's habit (as a regular caffeine-consumer or a non-caffeine consumer) may have significantly contributed to the difference in the effect of the treatments on cognitive performance.

In light of the high variation during the higher cognitive load tasks, a multivariate statistical analysis was conducted comparing scores between the habitual coffee drinkers and the non-coffee drinkers during the 2-back and 3-back tests (medium and high cognitive load tasks) to explore the possibility that these two groups may have benefitted more from different treatments. A 2-way ANOVA between treatment and habit showed higher scores on the 2-back task for non-coffee drinkers after consuming caffeine ($p=0.007$) (Fig. 2). However, there was no significant difference found between groups on 3-back scores (results not shown).

Discussion

The aim of this study was to address the synergistic effect of caffeine and sugar on working memory capacity by using a practical vehicle, a cup of coffee, which simulates a real-world scenario more closely than in past research. We also hoped to address the many recommendations for follow-up research suggested by previous studies: a larger, within-subjects design (Serra-Grabulosa et al. 2010); more realistic doses of caffeine and glucose (Smit and Rogers 2000); and inclusion of accessory factors such as smell, taste (Adan and Serra-Grabulosa 2010) and "mouth-feel" (Scholey and Kennedy 2004).

No synergistic effect was found between caffeine and sugar, and sugar alone had little effect on cognitive performance. A repeated-measures ANOVA showed a significant difference between scores, within subjects, across treatments, suggesting that there was a significant cognitive benefit to drinking coffee with or without sugar, particularly to those participants who were not regular coffee drinkers. Furthermore, there was a slight trend towards greater benefit to non-coffee drinkers when they received the caffeine and sugar treatment than when they received only the caffeine. These findings suggest that a larger sample size may have yielded a significant difference, thereby supporting the idea

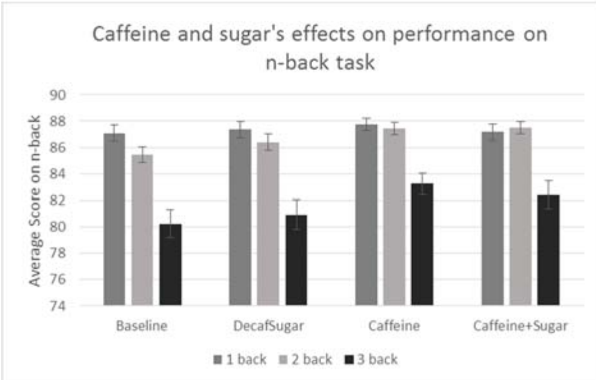

Figure 1. Scores from performance on n-back task for 1-back, 2-back, and 3-back under each treatment: baseline (no caffeine or sugar), decaffeinated coffee with 15 g sugar, caffeinated coffee (~125 mg caffeine) with no sugar, and caffeinated coffee with 15 g sugar (n=24). Values (mean +/- 1 s.e.) represent scores within each treatment and test, with 90 being a perfect score.

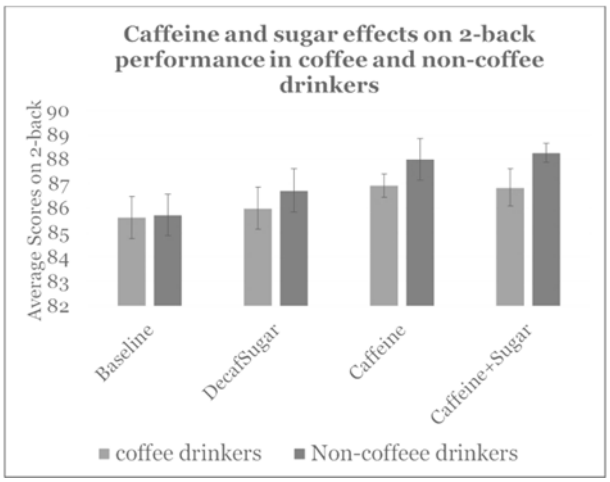

Figure 2. Scores from performance on 2-back task under each treatment (baseline, decaffeinated coffee with sugar, caffeinated coffee only, and caffeinated coffee with sugar) for each of the two groups: regular coffee-drinkers and non-coffee drinkers (n=24). Values (mean +/- 1 s.e.) represent scores within each treatment and test, with 90 being a perfect score.

of a possible synergistic effect between caffeine and sugar when taken together.

Conversely, most participants who were regular coffee drinkers saw more benefits to drinking coffee alone than with sugar. This may have been a function of the caffeine deprivation from the 12-hour fast being more detrimental to regular coffee drinkers during the baseline test than to non-coffee drinkers. These findings also support our hypothesis that the two groups (regular and non-regular coffee drinkers) respond differently to the treatments due to coffee drinkers' habituation to the beneficial effects of caffeine.

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