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Feeling smart: Effects of caffeine and glucose on cognition, mood and self-judgment

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HIGHLIGHTS

- Caffeine and glucose affect cognitive performance like placebo, water or no treatment controls in a multi-task setting.
- Participants feel preserved mental energy after caffeine and, by trend, coffee placebo consumption throughout a 2-h test.
- These subjective effects were stronger after 24 h caffeine abstinence.

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ABSTRACT

During education and early career, young adults often face examinations and assessment centers. Coffee and energy drinks are convenient and commonly used to enhance or maintain performance in these situations. Whether these macronutrients improve performance in a demanding and drawn-out multi-task situation is not clear. Using double-blind, placebo-controlled studies, we set out to examine the effects of caffeine and glucose in an assessment center-like situation, under natural consumption conditions, in a group of young adults who were heterogeneous with respect to consumption patterns. We measured multi-task performance including logical thinking, processing speed, numeric and verbal memory, attention and the ability to concentrate, and mood over a two-hour period. Caffeine and glucose were administered in common beverages with appropriate placebo controls allowing the assessment of psychological effects of expectancy. Importantly, and in contrast to most previous studies, participants retained their habitual caffeine and sugar intake (studies 1 and 2) as this represents common behavior. Based on the bulk of literature, we hypothesized that (i) caffeine enhances attentional performance and mood, while performance in more complex tasks will remain unchanged, and that (ii) glucose enhances performance on memory tasks accompanied with negative mood. Our results provide evidence that neither caffeine nor glucose significantly influence cognitive performance when compared with placebo, water, or no treatment controls in a multi-task setting. Yet, caffeine and, by trend, placebo improve dispositions such that participants perceive preserved mental energy throughout the test procedure. These subjective effects were stronger after 24 h caffeine abstinence (study 3). Future studies will have to address whether these mood changes actually result in increased motivation during a challenging task.

1. Introduction

How do students make sure they keep their performance at a high level during a long and demanding exam? Some swear by the "awakening effect" of coffee, others seek "food for the brain" by eating something sweet. For many people glucose and/or caffeine are essential and enjoyable aspects of everyday life. However, can these nutrients really enhance cognitive performance? Or do they just have psychological effects? Or is there no effect at all?

Caffeine (1,3,7-trimethylxanthine) is the world's most consumed psychostimulant. It is contained in coffee, tea, energy drinks, and several soft drinks. After oral consumption, caffeine is quickly absorbed in the gastrointestinal tract and the highest blood concentrations are reached after 30–60 min. The half-life time of caffeine in the human body amounts to 3 to 3.5 h on average, but shows high inter-individual

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variation [1]. Similar caffeine concentrations have been found in the blood and in the cerebrospinal fluid, indicating that the blood brain barrier is no obstacle for caffeine [2]. Physiologically, caffeine impedes the binding of adenosine to its receptors in the cell membranes [3], and thus causes a mild dilation of blood vessels and increases in blood pressure, metabolic rate, and urine production [4]. Augmenting effects include increased alertness and reduced fatigue, leading to better performance especially in simple psychomotor tasks demanding fast reactions [5,6]. Transferred to real-life situations, caffeine has been shown to improve, for example, steering accuracy, and reduces the number of incidents in a driving simulator [7,8]. However, for more complex and cognitively demanding tasks, the effects of caffeine appear inconsistent and reports of increased performance in demanding tasks [9] coexist with null findings [10]. It has been suggested that inconsistent effects under high cognitive loads are caused by interactions between baseline arousal state, dose and inter-individual differences (see [11]). For example, moderate doses of caffeine to rested individuals have led to heightened vigilance and faster reaction times while cognitive functions such as memory or learning were unaffected [6]. In contrast, fatigued and exhausted participants showed improvement in working memory after caffeine compared to placebo administration, although the effects were likely attributable to the restored ability to sustain attention during the task rather than to direct improvement in working memory [12]. Subjective effects of caffeine also include increased feelings of wellbeing, mental energy, motivation, and self-confidence [13–15]. According to the withdrawal reversal hypothesis, such benefits for subjective experience and mood merely reflect the restoration to normal levels thereby compensating the detrimental effects of caffeine withdrawal in regular consumers (see [16]). Together, diverse and partly inconsistent findings render a comprehensive view on the beneficial effects of caffeine difficult. Particularly, the use of specific tasks and target groups, e.g. high vs. non-caffeine consumers, places limits on generalization.

The carbohydrate glucose can be found in many of our comestibles, especially sweet ones. Glucose is the major source of energy for the human brain; it is essential for the normal functioning of the central nervous system [17]. The brain relies on a constant blood glucose level, since its energy storage is very small. Although all brain functions are primarily dependent on the availability of glucose, it has been found that especially effortful, controlled, and executive processes are in need of a sufficient supply with glucose [18–20]. When measuring cognitive performance, glucose has been shown to improve attention, speed of processing, and working memory [21–23], for example in solving maze problems, or verbal fluency [18]. However, the most consistent effects of glucose on cognitive functioning have been found for the facilitation of declarative memory [24,25] leading to the hypothesis that the hippocampus plays an important role in the pathway through which glucose acts on cognitive functions in the brain [25]. Also affective mood changes correlated with blood glucose levels [26]. Especially perceived mental energy is reduced as blood glucose levels decrease [27], and elevated when the glucose metabolism in the brain is higher as well [28]. Furthermore, after performing a Stroop task for 30 min, a faster decrease of glucose levels in the blood led to increased ratings of sadness [29]. The existing bulk of studies suggests only a brief time window for beneficial effects of glucose to occur. This is surprising, as, in healthy individuals, plasma glucose concentrations peak within 60 min after glucose ingestion and return to baseline levels only within 2–3 h [30]. Therefore, it remains difficult to infer about glucose effects in multi-task settings that require sustained performance.

During education and early career, young adults face situations that require various cognitive functions, like examination and assessment centers. Coffee and sweetened energy drinks are convenient and popular means to supposedly enhance performance in these situations. The potency of caffeine and glucose to exhibit effects on performance and mood in young adults was investigated with the present series of three studies.

In the first study, we examined the effects of caffeine and glucose in a multi-task setting on a range of cognitive tasks and mood in healthy young individuals. Caffeine and glucose were administered in common beverages with appropriate placebo controls to control for the psychological effects of expectancy, which have been neglected surprisingly often [31]. We hypothesized that (i) caffeine improves attentional performance and mood, while performance in more complex tasks will not be improved, and that (ii) glucose enhances performance on memory tasks, potentially accompanied with negative mood.

Whether the findings of the present study can be explained by a placebo effect (i.e., a psychological effect) or the lack of dietary restraints for the active ingredients, was addressed in studies 2 and 3, respectively. In study 2, we asked whether a placebo treatment compared to plain water is sufficient to enhance mood and/or performance due to psychological expectation-based effects as about the enhancing or activating properties of coffee and energy drink. In study 3, we asked whether (i) caffeine effects occur after a 24-hour caffeine withdrawal and (ii) we compared placebo to no treatment to rule out effects of hydration.

2. Materials and methods

2.1. Ethics Statement

The experimental protocol conformed to the World Medical Association's (WMA) revised Declaration of Helsinki [32] and was approved by the ethics committee of the German Psychological Society (KO-062012). Participants gave their written informed consent prior to participation and received a monetary compensation.

2.2. Study 1

2.2.1. Participants

Healthy male adults were recruited through bulletins at local universities and public places. We recruited only men to avoid confounding interactions of caffeine metabolism with reproductive hormones that vary across the female cycle [33,34]. Seventeen normal weight (body mass index [BMI]: mean = 23.8, $SD = 3$) men aged 19–40 years (mean = 28.5, $SD = 4.4$) completed the study. Participants reported to be healthy. Their quotidian consumption of caffeine and sugary drinks was assessed based on the daily intake of coffee, tea, coke, and energy drinks, and the intake of juice, soda and other sweet drinks, respectively (Table 1). Importantly, participants were allowed to consume their regular amounts of caffeine or glucose up to 2 h prior to testing thereby maintaining their habitual intake behavior and thus avoiding withdrawal symptoms. Then, participants were instructed to refrain from eating and drinking anything but water.

2.2.2. Design and procedure

The effects of caffeine and glucose on cognitive performance and subjective mood were tested in a double-blind, balanced, placebo-controlled within-subjects design. For this, participants received two drinks labeled “coffee” and “energy drink” at the same time. Two versions, one containing an active ingredient (caffeine or glucose) and one without the active ingredient (placebo), were prepared for each drink. Participants were naïve as to the different compositions and unable to discriminate the active and placebo conditions, as we had asked them after completion of the study whether they had noticed any differences in taste or flavor between the respective drinks, which was never the case. These findings are in line with a pilot study ($N = 5$). The composition of the two drinks differed across treatment conditions as follows: (1) the CAFFEINE treatment consisted of a decaffeinated coffee with added caffeine and an artificially sweetened placebo drink; (2) for the GLUCOSE treatment, a decaffeinated placebo coffee and a glucose drink were administered; (3) in the PLACEBO condition, subjects received a decaffeinated coffee and an artificially sweetened drink. All beverages were based on distilled water. The PLACEBO coffee was prepared using 2 g of decaffeinated instant coffee powder