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The Association Between Caffeine Intake and the Stroop Effect

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Abstract: Caffeine consumption is closely related to different aspects of life. With different cultures and different routines, caffeine consumers will form their own habits of consumption. Inhibition control will be affected by caffeine consumption. It is an important executive function for human beings. The Stroop Effect is a classic cognitive phenomenon which exists from The Stroop Colour and Word Test (SCWT), to explore the interference between automatic and controlled processing of information. Caffeine as an attention enhancer, helps to increase the speed of making decisions and the rate of detecting stimuli. This review paper aims to investigate the potential correlation between caffeine intake and performance on the Stroop task. By reviewing the most recent research paper in this field, the impacts of caffeine consumption manipulating the Stroop task result were summarized and interpreted. The overall effect of caffeine intake on attentional control is supported by attentional control after caffeine intake, this includes the evidence of cognitive behaviour outcomes and neuroimaging. In addition, the overall effect depends on the dosage of caffeine intake, with different dosages, the test result will be significantly different. Results show that caffeine consumption will influence attentional control, mainly refleted by Reaction Time (RT), neuroimage and depends on the dosage. However, individual differences will highly affect the caffeine absorption. The outcome of this research will have implications for future research exploring the Stroop task performance help to evaluate the other sides of cognitive control, such as emotional control.

Keywords: caffeine consumption, Stroop task, cognitive behaviour

1. Introduction

Caffeine acts as a stimulant, enhancing activity within the brain and nervous system while also elevating the circulation of substances like cortisol within the body. When consumed in modest amounts, caffeine can induce feelings of alertness and concentration. Numerous studies have extensively documented the advantageous impacts of caffeine across a range of information-processing tasks. Specifically, in tasks requiring sustained attention and the detection of occasional target stimuli, caffeine constantly enhances both the speed and rate of detection. Caffeine has been recognized as an attention enhancer, the underlying mechanism elucidated in this study likely pertains to caffeine's capacity to counteract adenosine receptors within the cerebral domain, thereby eliciting escalated neuronal functionality and neurotransmitter discharge, notably dopamine and

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norepinephrine, which consequently augment facets of attentional proficiency, including vigilance and concentration.

Individuals can adjust their caffeine intake based on the perceived benefits and possible disadvantages of different doses. In a previous review, it was indicated that although caffeine may lead to mild dependence, it provides advantages such as heightened alertness, attention, cognitive function, and mood enhancement [1]. Moderate caffeine consumption, defined as an intake of less than six cups per day, has been linked with decreased depressive symptoms, a lower occurrence of cognitive lapses, and a reduced likelihood of suicide. Nevertheless, excessive caffeine intake can result in psychotic and manic manifestations, as well as anxiety, especially in individuals with panic disorder and social anxiety disorder. Initial findings propose potential efficacy in certain individuals with obsessive-compulsive disorder (OCD).

The Stroop Colour and Word Test (SCWT) is a neuropsychological assessment tool aimed at evaluating an individual's capacity to suppress cognitive interference [2]. The Stroop task is comprised of two conditions, they are congruent condition and incongruent condition. The task aims to detect the difference in performance between two conditions, the interference patterns are governed by the comparative potency of the functional associations between input and output representations. For instance, the linkage between colour-word stimulus input and the inclination to read the word is more robust compared to the linkage between the same input and the inclination to identify the colour in which the word is appearing with.

Under both conditions, participants were instructed to identify the colour of the ink rather than the semantic meaning of the word. For the congruent condition, the irrelevant information either does not elicit the conflicting response tendency or does so to a diminished degree, so it is comparatively neutral. However, in the incongruent condition, two spatially aligned pieces of information are simultaneously presented, wherein one specifies the required response for the task which is the word meaning, while the other is the ink colour elicits a conflicting response inclination that necessitates suppression.

SCWT has been widely employed as a task with highly reliable and stable measures of individual differences. Utilizing a straightforward data collection approach, this assessment has been employed across a diverse array of research endeavours and has demonstrated noteworthy associations with various other factors. A previous investigation examined the convergence of skilled word identification, spatial attention, and the Stroop effect. By conducting a sequence of experiments, the findings, in conjunction with prior research, imply that spatial attention's default allocation in visual word recognition spans the entirety of the word. Spatial attention was procured to be limited by a single letter position, potentially impeding word recognition activation. Consequently, this narrowing reduces or obstructs the Stroop effect's manifestation, contingent upon contextual nuances. Contrary to prevailing assumptions of its automaticity, the Stroop effect is better construed as influenced by default settings within word recognition and attentional mechanisms. The study also highlights certain associations between consciousness, contextual factors, and cognitive control [3]. The reaction time (RT) exhibits a deceleration when the word and colour are incongruent. Stroop interference conventionally quantifies the disparity in RT between the word-colour sheet (where Stroop words appear in non-matching ink colour) and the neutral sheet (featuring colour patches). It is calculated by the difference in RTs between neutral and incongruent trials.

Research investigating the impact of stimulants on Stroop interference has produced some inconclusive findings. Attentional control is important in people’s daily life, caffeine consumption is closely related to it and has been realized as a possible factor which might modify the result of SCWT. Moreover, caffeine has been recognised and stands as the predominant psychoactive substance employed globally, with coffee serving as the primary conduit for its ingestion in Western dietary

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practices. Thus, the researcher decided to review and detect the correlation between caffeine consumption and the manifestation of the Stroop effect.

2. Effected Attentional Control after Caffeine Intake

2.1. Evidence of Behavioral Outcomes

Caffeine as an attention enhancer, caffeine intake might affect attentional control and it will mainly be reflected by behaviour patterns after consuming it, studies yielded evidence indicating that caffeine ingestion will lead to degrees of enhancements in response accuracy and speed, thus lowering the Stroop effect. The study aimed to explore how caffeine intake and the prospect of reward interact to influence cognitive performance and neural activity [4]. Thirty-one participants were invested in this study. After consuming differentiated amounts of caffeine and the placebo according to their body weight, they completed a cued-reward cognitive task which is the colour-word Stroop task. Their neural activity was monitored concurrently using electroencephalography (EEG). This investigation revealed that both caffeine consumption and the anticipation of rewards enhanced both the accuracy and speed of responses. Preparatory attention, indicated by an enlarged frontocentral slow wave (CNV) and reduced posterior alpha power, was enhanced with reward prospect. This enhancement was more pronounced with caffeine intake compared with placebo consumption. These effects were primarily observed in preparatory attention triggered by the cue. Additionally, caffeine facilitated neural mechanisms associated with attentional preparation and processing of stimuli, particularly for task-relevant information. Overall, the findings suggest that both caffeine intake and the prospect of rewards contribute to improvements in cognitive performance, with caffeine exerting a more pronounced effect on attention before the appearance of stimuli and neural processing.

The findings measured above have proven caffeine consumption can boost cognitive behaviour, but there is significant variability observed among individuals. For example, genetic factors may contribute to individual differences in their cognitive responses to caffeine consumption. Researchers assessed cognitive responses to caffeine across three intricate cognitive tasks, each targeting distinct aspects of attention [5]. Assessment of Alerting and Orienting was conducted through Categorical Search Task, while Executive Control was evaluated by implying the Stroop Task and Eriksen Flanker Task. Researchers aimed to investigate whether responses were influenced by genetic variations influencing adenosine metabolism or catecholamine receptors. This study encompassed 106 male participants and employed a double-blind design, participants consumed caffeine and a placebo before performing cognitive tasks, and with 24 hours between both conditions, the protocol was replicated using the alternative preparation. A significant decrease of RT was found after caffeine consumption, thus, enhancing the level of attention within the investigated domain. Another finding showed there exists considerable inter-individual variability in cognitive performance responses to caffeine. In conclusion, this variability in attentional response may, in part, be elucidated by genetic polymorphisms of adenosine and adrenergic receptors.

As indicated by the above findings, consuming caffeine generally enhanced the Stroop test performance with respect to deduction in RT, but different individuals with different inheritable factors might have different levels of absorption and experience different levels of cognitive behaviour enhancement. Other than the research on cognitive control, the potential association between coffee consumption and cognition is a substantial of research interest. There was a study assesses the correlation between coffee intake, along with overall dietary caffeine consumption, and the likelihood of impaired cognitive function within a group of elderly overweight or obese individuals diagnosed with metabolic syndrome [6]. Utilizing a cross-sectional design, 6427 participants were recruited for this investigation in total. A baseline assessment included the administration of a food frequency questionnaire to gauge coffee consumption and total dietary

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caffeine intake. Subsequently, participants underwent either the Mini-Mental State Examination (MMSE) or a battery of neuropsychological assessments. The findings suggested a positive association between coffee consumption and total dietary caffeine intake, and improvement of cognitive performance, as evaluated by diverse neuropsychological assessments, among a Mediterranean population of elderly individuals diagnosed with metabolic syndrome. caffeine consumption can significantly help to improve brain functions such as attention.

Coffee as a brain stimulant, has the function of enhancing alertness. It can also maintain arousal, increase executive speed, sustain vigilance, and promote memory. These characteristics are associated with attention, mood, and cognitive function. Functional near-infrared spectroscopy (fNIRS) is utilized as a noninvasive optical method to monitor brain activity in the prefrontal cortex region. The study investigated the effect of caffeine intake on attentional control and inhibition control [7]. Participants performed a colour-word Stroop task behavioural experimental research. The study results indicate that coffee can effectively modulate task performance according to feedback information as evidenced by decreased RTs and increased accuracy rate. Furthermore, fNIRS findings reveal noticeable brain activity in the bilateral ventrolateral prefrontal cortex (VLPFC) regions, with variations in brain activation regions observed under different coffee conditions. Under highly effective light conditions with caffeine intake, VLPFC was activated, the change mainly happened in L-VLPFC. To interpret, caffeine will enhance brain function reflected by task performance of reducing RT and the error rate, at the same time, some of the brain regions will be activated after caffeine consumption.

There is some evidence supporting that caffeine might improve cognitive performance measure by the Stroop test. Have another sentence, when the dosage is too high, caffeine consumption might bring out negative effects. In the study in 2023, the immediate effects of caffeine intake on the Stroop test performance before and after repeated small-sided games (SSG) among professional soccer players were assessed [8]. Participants were involved in both condition, some of them took caffeine first and others took a placebo first. In a randomised crossover double-blind placebo-controlled trial, they consumed either caffeine (5 mg/kg) or a placebo 45 minutes before engaging in a protocol. The Stroop test was conducted immediately before and after the exercise protocol. This study found that there was an increased perceived exertion during SSGs, with no difference between caffeine and placebo consumption. The exercise protocol led to significantly faster responses on the Stroop test but did not affect accuracy. However, caffeine intake resulted in slower reaction times and reduced accuracy during the congruent but not incongruent trials, the error rate increased in both trials after caffeine consumption. Indicating a detrimental effect of caffeine on cognitive performance in this context. Thus, while the performance in the Stroop test was enhanced by the exercise protocol, acute caffeine ingestion proved to be disadvantageous.

2.2. Neuroimaging Evidence

Besides a variety of behavioural evidence indicating that caffeine consumption will help to manipulate cognitive ability, neuroimaging evidence can also support the argument that caffeine consumption will influence attentional control. A previous research aimed to detect whether threat bias is affected by caffeine intake and whether the Threat Bias Ratio (TBR) manipulates this influence [9]. Participants underwent testing following the administration of a placebo and 200 mg of caffeine. The emotional component is added in attentional control, a pictorial emotional Stroop task containing positive, neutral and negative emotional-related pictures, served as the measure of threat bias. There was a negative correlation between TBR and the interference effect. With longer RTs responding to trials including emotion-related pictures, the score of interference is positive, which means that cognitive ability increased when facing the picture. Findings indicated that at baseline and post-placebo, baseline TBR exerted a direct influence on threat bias, further emphasising that TBR is an

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electrophysiological indicator for executive control. This notion suggests that frontal TBR may serve as a valuable proxy for individual variances in baseline prefrontal catecholamine function, particularly in conjunction with trait anxiety, notably for negative imagery. It also confirms that caffeine can affect attentional control over automatic threat-attention depending on baseline individual differences. For individuals with different baselines, they will exhibit a variety of levels of attentional control. To further explain this result, frontal TBR is an essential part of the regulation of negative emotions such as anxiety and depression. After caffeine intake, will impact attentional control but depends on different individuals. There are some evidence showing caffeine intake has an effect on attentional control. These can be reflected by the cognitive Stroop test result, but acute caffeine ingestion will bring some negative effects. In addition, different individuals have different levels of caffeine absorption and genetic factors will also influence the attentional controlling ability.

3. The Impact of Dosage

The dosage of caffeine intake is another important factor which might cause differences for cognitive behaviour. Researchers. conducted a study to examine the impact of varying levels of caffeine consumption on both cognitive function and neural activation patterns in 2020 [10]. Ten male participants, who were deemed healthy, consumed either a placebo or varying doses of caffeine according to their body weight. The impact of each treatment condition was assessed through Stroop tasks, which were conducted before and 60 minutes following caffeine ingestion. The result showed that except for the higher dosage, the other two levels (3 and 6 mg/kg body weight) significantly reduced RT during the incongruent stimuli in Stroop tasks, while only the 3 mg/kg dose decreased RT for congruent stimuli. However, the accuracy of responses was not affected by caffeine. Under the congruent stimulus condition, ingestion of 3 mg/kg of caffeine led to a significant increase in oxygenated hemoglobin (HbO) levels in several areas of the prefrontal cortex. No significant effects on HbO levels were observed under the incongruent stimulus condition. In general, low-dose caffeine may exert a more substantial influence on cognition and brain activation, specifically by enhancing executive function and prefrontal activities. This effect is often reflected in shorter RT during tasks such as the Stroop effect, while the error rate remains consistent.

To further analyse the impact of dosage of caffeine on attentional control, Wang et al.'s study was reviewed [11]. They conducted a study to explore the effects of dosage of caffeine intake (low, moderate, and high doses) on both intermittent exercise performance and cognitive function. This was a cross-over, double-blind preliminary investigation, 10 male participants completed a familiarisation session followed by 4 experimental trials. After either caffeine and placebo condition, participants did exercise, followed by a period of rest. Subsequently, they engaged in cycling activity consisting of maximal power pedaling, interspersed with unloaded pedaling and rest intervals. Participants completed the Stroop task prior to capsule ingestion, 1-hour post-ingestion, and after exercise. Mean power output (MPO), peak power output (PPO), and response time (RT) in the Stroop task were assessed. The study's results suggest that low-dose caffeine consumption has a more significant positive effect on subjects' physical endurance during extended intermittent exercise and cognitive performance when contrasted with moderate or high doses of caffeine. In this way, to achieve better performance, individuals should consume lower doses of caffeine, otherwise, the outcome of performance will be negatively affected.

4. Conclusion

To conclude, this study seeks to contribute to the understanding of how caffeine consumption may impact cognitive processes related to attention. Caffeine intake would effectively affect attentional control, this could be shown by the decrease in RT in the Stroop test. However, acute consumption

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of caffeine might not enhance cognitive behaviour, and the degrees of enhancement were based on genetic factors and there were strong individual differences. The neuroimaging technique provided evidence suggesting that certain brain regions might be affected after caffeine consumption for the improvement of attentional control. Furthermore, the dosage of caffeine intake played an important role in attentional control. With certain levels amount of caffeine intake (3 and 6 mg/kg body weight), cognitive behaviour might be facilitated. However, when individuals consumed overdose, it will not help to regulate attention, for the Stroop task result, the Stroop effect could not be overcome effectively.

This review paper has two main limitations, for reviewing studies focusing on dosage, there is no neuroimage to support the argument that dosage of caffeine intake is another significant component which might impact cognitive behaviour. The brain region activated with different amounts of dosage cannot be directly reflected via brain scan.This paper does not investigate regular caffeine consumers, for this group of people, who might be addicted to caffeine, it might be the element to maintain their normal cognitive behaviour level, but cannot enhance their cognitive behaviour to reach a higher level of accuracy and lower RT which stands for focusing attention. Future research direction can be detecting how would the Stroop task performance help to evaluate the other sides of cognitive control, such as emotional control.

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