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# Can a cup of black coffee enhance cognitive function and short-term memory?

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**Abstract:** *Background:* The stimulatory effects of coffee on the central nervous system (CNS) have been well studied. There exists, however, no conclusive data on the effects of the consumption of coffee on short-term memory. *Objectives:* This study's objective was to determine the effects of coffee on short-term memory and on certain recent tests of cognitive function such as digit symbol substitution test (DSST) and letter cancellation. *Methods:* The study involved a single group of fifty male subjects aged between 18 and 25. The subjects underwent a set of baseline tests that included estimation of visual and auditory reaction time, tests of cognitive function such as letter cancellation and digit symbol substitution test (DSST), and tests of short-term memory such as immediate word and immediate object recall. They were then given a cup of black coffee and fifteen minutes later the same set of tests were performed. *Results:* It was observed that there was a significant shortening of the visual ($p<0.001$) and auditory reaction time ($p<0.001$), and the time taken for letter cancellation ($p<0.001$) and DSST ($p<0.001$) after coffee. There was an increase in the number of objects recalled that approached statistical significance ($p=0.082$), but no obvious effect on the number of words recalled. *Conclusion:* The above observations seem to indicate that coffee improves cognitive and psychomotor function, may improve the ability to recall visual information but plays no role in the recall of auditory information.

**Keywords:** Cognitive function, DSST, Letter cancellation, Reaction time, Short-term memory.

## Introduction

Coffee, a beverage brewed from the roasted seeds of the coffee plant, is one of the world's favorite caffeinated drinks. Caffeine, the pharmacological compound present in coffee, is considered to be the most consumed naturally occurring drug [1]. Caffeine temporarily wards off drowsiness, stimulates alertness and counters fatigue. The level of alertness can be clinically determined by estimating the reaction time which is the time taken to react to a specific stimulus. Researchers have demonstrated that caffeine shortens the visual and auditory reaction time [2].

Studies on the effect of caffeine on short-term memory have presented inconclusive results. While some studies demonstrate that caffeine has a beneficial effect on short term memory [3-4] most others report that caffeine has either no effect on recall performance [5] or actually impairs short-term memory [6]. This lack of clarity is probably due to the amount of caffeine administered, the time of consumption, the subject populations, and the recall tasks employed. Although the acute effects of coffee on cognitive and psychomotor function have been well documented, its effect on short-term memory is yet to be conclusively demonstrated. The purpose of this study was to determine the effects of a regular cup of black coffee on short-term memory and on certain tests of cognitive function in young south Indian males. As coffee is consumed in large amounts every day by people around the world, the relevance of this study does not need to be emphasized.

## Material and Methods

*Study design and participants:* This interventional study was conducted between August 2009 and March 2010 in the Department of Physiology, Pondicherry Institute of Medical Sciences (PIMS), Pondicherry, south India. Fifty healthy young adult males from the technical staff of the institute volunteered. The subjects were

 

between the ages of 18 and 25 and drank less than 4 cups of coffee or tea or less than two 300 ml bottles of caffeinated soft drinks per day. Individuals with systemic illnesses, sleep disturbances, neuro-muscular disorders, psychiatric illness, peptic ulcer and rhythm abnormalities of the heart were all excluded. Smokers and those who consumed more than 2 units of alcohol per week were also excluded. A written informed consent from the participants and clearance from the institute's research and ethical committees was obtained prior to the commencement of the project.

*Procedure:* Subjects were instructed to have a light breakfast (less than 250 calories), without coffee or tea at 7a.m on the morning the recordings were performed. The recordings commenced at 9a.m and were performed in a quiet dimly-lit room, with an ambient temperature that varied between 37 and 38°C over the duration of the study. Anthropometric measurements such as height and weight were first recorded and the body mass index (BMI) was calculated.

*Estimation of visual and auditory reaction time:* The reaction time was estimated with the help of an electronic reaction timer (Anand agencies Pune, India), capable of measuring reaction times accurate to the millisecond. The subject, seated comfortably on a stool, was asked to keep pressing a button with the index finger of his dominant hand. He was instructed to remove his finger as soon as a red light flashed. Three sets of 5 recordings each were performed and the average thus obtained was taken as the visual reaction time of the subject. The auditory reaction time was similarly estimated by providing an auditory stimulus. The subject was familiarized with the procedure a few times before the actual recordings commenced.

*Letter Cancellation:* The subject was provided with a piece of paper containing 26 jumbled letters of the English alphabet. The black letters printed on a white back ground were large and evenly spaced out. The investigator called out 10 letters in no particular order. The subject was instructed to cancel the appropriate letter as soon as he heard it being called. The time taken from calling to cancellation of all 10 letters was timed with a stop watch (accurate to the millisecond).

*Digit Symbol substitution test:* A hundred random numbers were electronically generated and printed out on a piece of paper. The subject was instructed to draw a circle over even numbers and a triangle over odd numbers. The time taken by the subject to substitute a symbol for all the 100 digits was noted.

*Immediate Word recall:* This task involved the investigator reading out 20 words in the same tone of voice and at a constant rate of one word every 2 seconds. Immediately after this, the subject was required to recall and write down as many words as possible from memory in the given time of 60 seconds.

*Immediate Object recall:* In this memory task, 20 objects were placed on a table in front of the subject. The objects ranged from picture cards to miniature animals to house hold objects. The subjects were given 15 seconds to view the objects before they were taken away. The subjects were then instructed to write down as many objects as possible from memory within 60 seconds.

After the baseline tests the subject was instructed to consume the coffee which was prepared as detailed below.

*Preparation of coffee:* Ten grams of Nescafe Classic instant coffee powder (containing 106 mg of caffeine) and 10gms of sugar were added to 200 ml of boiling water taken in a cup. Milk was avoided so as to prevent the precipitation of compounds. The contents were cooled to 55°C before being offered to the subject. The subjects were then instructed to drink it within two minutes.

*Post-consumption testing:* Fifteen minutes after consumption the same set of tests were repeated in the same order [7].

*Statistical analysis:* The results obtained were analyzed using Student's paired t test for all variables and are expressed below as Mean ± SD.

## Results

The fifty male subjects had a mean age of 20.9 ± 2.78 yrs. Their anthropometric measurements are furnished in Table 1.

| Table-1: Anthropometric measurements | |
|---|---|
| **Parameter** | **n = 50** |
| Ht (m) | 1.66 ± 0.25 |
| Wt (Kg) | 63.66 ± 11.66 |
| BMI (Kg/m2) | 22.9 ± 4.2 |
| All data are expressed as Mean ± standard deviation. Ht: height in meters, Wt: weight in kilograms, BMI: body mass index | |

The mean visual reaction time was significantly shortened ($p<0.001$) after the consumption of coffee (Table 2). A significant shortening ($p<0.001$) of the mean auditory reaction time was also observed (Table 2). The time taken by the subjects to cancel all the ten letters that were called out was significantly shortened ($p<0.001$) after coffee (Table 2). A significant shortening ($p<0.001$) of the time taken for substituting an appropriate symbol for all the hundred digits was also noticed (Table 2). The number of objects recalled after coffee was increased (Table 2). This increase approached significance ($p =0.082$). The consumption of coffee, however, had no significant effect on the number of words recalled (Table 2).

| Table-2: Effect of coffee on cognitive and psychomotor tests | | | |
|---|---|---|---|
| **Parameter** | **Before coffee (n = 50)** | **After coffee (n = 50)** | **P-value** |
| Visual reaction time (ms) | 197 ± 23.77 | 171 ± 14 | <0.001 |
| Auditory reaction time (ms) | 166.3 ± 14.76 | 152 ± 12 | <0.001 |
| Letter cancellation (s) | 25.6 ± 6.31 | 22 ± 5.6 | <0.001 |
| DSST (s) | 117.4 ± 24.92 | 93 ± 20 | <0.001 |
| Immediate word recall | 9.6 ± 2.68 | 9.4 ± 2 | 0.466 |
| Immediate object recall | 11.36 ±2.72 | 12 ± 2.6 | 0.082 |
| All data are expressed as Mean ± standard deviation. Visual and auditory reaction times are expressed in ms (milliseconds).Letter cancellation is expressed as the time in seconds taken to cancel 10 letters. DSST (digit symbol substitution) is expressed as the time taken in seconds to substitute an appropriate symbol for 100 digits. Immediate word and immediate object recall are expressed as the number of words or objects recalled in one minute. | | | |

## Discussion

Coffee is one of the most consumed beverages in the world. Caffeine, the main pharmacological agent present in coffee, is one of the most widely used CNS stimulants A 150ml cup of coffee has been shown to contain anywhere from 40-180mg of caffeine [8]. After ingestion caffeine is rapidly absorbed from the gastrointestinal tract [9] and peak plasma concentrations are reached within 15 to 120 min [7]. Acting on the central nervous system (CNS), caffeine is known to cause an immediate but transient increase in the level of alertness. It exerts its stimulatory effect on the CNS by blocking the action of adenosine on $A_1$ adenosine receptors present in the hippocampus, [10] and $A_{2a}$ receptors found in the nucleus accumbens [11].

Researchers have demonstrated that caffeine increases metabolism in the reticular formation and raphe nucleus [12]. By stimulating the areas in the brain concerned with the sleep-wake cycle, caffeine promotes wakefulness and alertness. The level of alertness can be assessed clinically by estimating the reaction time which is the time between the application of a stimulus and the appearance of a response. The mean auditory reaction time has been found to be 140-160 ms and the mean visual reaction time is reported to be about 200 ms [13-14]. Miller and Low were of the opinion that the time for the motor response was essentially the same in all reaction time tests, implying that the differences in reaction time was due to the time taken for the central processing of information [15].

In the present study it was observed that both the visual and auditory reaction times were significantly shortened after coffee intake. In a similar study Lieberman concluded that both the auditory and visual reaction times were

significantly shortened after ingesting 32 mg of caffeine [16]. Other researchers have reported similar results [17]. It was demonstrated that the consumption of coffee not only shortened the reaction time, but also reduced the effect of distraction, thereby implying that caffeine improved concentration [18].

The author is not aware of any previous study that has investigated the effects of coffee on tests of cognitive function such as DSST and letter cancellation. DSST involves substituting a symbol for random numbers and is a test of speed of information processing. The time taken for DSST is influenced by age, [19] the basic level of education, [20] and diseases such as diabetes [21].

Letter cancellation tests the speed at which the subject can cancel out letters as soon as they are called out. DSST and letter cancellation are simple yet sensitive neuropsychological tests used to objectively evaluate cognitive function. In the present study coffee was observed to produce a statistically significant shortening in the time taken for DSST and in the time taken for letter cancellation. The cognitive enhancement, shortening of the reaction time and increase in the level of alertness after coffee are indicative of the role of caffeine as a CNS stimulant. The effect of caffeine on memory, though, is not entirely clear.

Memory is classically divided into short-term and long-term memory. Short-term memory, otherwise referred to as working memory, can store a limited amount of information for a brief period of time. Researchers are of the opinion that separate pathways are employed in the encoding and retrieval of short-term memory. The left prefrontal cortex is involved in encoding short-term memory while retrieval involves the right prefrontal cortex [22].

Buckner studied the pathways involved in the immediate recall of words and pictures using Positron Emission Tomography (PET) scans, and was able to demonstrate that the right anterior prefrontal area was involved [23]. Short-term memory is usually tested by free recall tests. In immediate recall tasks subjects are generally presented a list of unrelated words and then instructed to recall as many words as possible in any order. The subject's linguistic knowledge, the order in which words are read out [24] and the length of the words can affect recall performance [25]. Jarvis in a study conducted on 9003 British adults, concluded that caffeine could improve incidental verbal memory [26] While some other studies similarly demonstrate that caffeine has a beneficial effect on short term memory, [3-4, 27] most others report that caffeine has either no effect on recall performance [5, 28-29] or actually impairs short-term memory [6].

The present study limited itself to the effects of coffee on immediate recall of words and objects. It was observed that there was a slight increase in the number of objects recalled after coffee but no effect on the number of words recalled. This improvement in short-term memory can probably be explained by the fact that caffeine is known to act on parts of the brain concerned with working memory. An animal study demonstrated that direct intra-hippocampal injection of an $A_1$ receptor agonist increased the number of errors in a test of working memory [30]. Hence caffeine, by blocking hippocampal $A_1$ receptors, [10] may actually be able to improve short-term memory. This is a possible explanation for the improvement in short-term memory observed in the present study.

## Conclusion

In conclusion, a cup of coffee enhances cognitive and psychomotor performance, may improve the ability to recall visual information but has no effect on the recall of auditory information. The objective of the present study was to demonstrate the effects of a regular cup of coffee on cognitive and psychomotor performance. This study involved a single group of subjects all of whom were given caffeinated black coffee. In retrospect the author is of the opinion that a placebo-controlled study using caffeinated and decaffeinated black coffee would have been a better study design.

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