DOES CAFFEINE CAUSE EFFECT ON SHORT-TERM MEMORY?

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ABSTRACT

Caffeine is known to wake you up and increase the concentration level. Through the experiments, we found that caffeine consumption helps to increase the level of concentration. However, it was not possible to define correlation between the concentration level and test scores. Therefore, to find the relationship between these indicators, it will be preferable to use more accurate sensors, improve software application, test scenarios and the number of experiment participants.

Key words: Caffeine, Short-term memory, Electroencephalography.

1. INTRODUCTION

Caffeine is one of the most widely used methylxanthine-based Central Nervous System (CNS) stimulants. Caffeine can be easily found in a variety of foods and drinks, although it is mainly consumed as coffee, tea or soft drinks. Depending on the types, one cup of coffee contains less than 200mg caffeine (Nehlig, 1999). The maximum recommended daily intake is 400mg (adult basis), to take 400mg of caffeine you need to drink 9.41 sticks of Maxim Mocha Gold Mild, or 3.5 cups of Starbucks tall size Americano with two shots. Caffeine is the most widely used psychotropic drug, without causes of serious harm to human health due to its misuse or abuse. Caffeine, unlike other psychoactive drugs, such as stimulant drugs (Amphetamine and cocaine), depressant drugs and hallucinogen (Lysergic acid diethylamide and Marijuana), is legal and unregulated in almost every country.

Caffeine is generally thought to provide benefits such as to relieve or prevent drowsiness and to arouse. Caffeine blocks adenosine action on receptors inside the body. As a result, our body prevents drowsiness caused by adenosine. Psychopharmacological studies investigated the different aspects of the effects of caffeine. Caffeine has been found to enhance mental performance, mood and vigilance (Brice and Smith, 2002; Lieberman *et al.*, 1987; Van Duinen *et al.*, 2005; Van Dongen *et al.*, 2001; Ramakrishnan *et al.*, 2014; Einother and Giesbrecht, 2013; Brunyé *et al.*, 2010). It happens because caffeine can easily cross the Blood Brain Barrier (BBB) and acts as a central nervous system stimulant (CNS stimulant), so you can experience alertness, good mood, and temporary euphoria (Haskell *et al.*, 2005).

Conversely, little is known about the effects of caffeine on transpulmonary administration. When consuming caffeine orally, the peak blood level of caffeine is shown in 30 minutes to 2 hours, whereas transpulmonary administration the peak blood level of caffeine is shown in few seconds (Blanchard and Sawers, 1983). These results suggest that caffeine will have an immediate effect on improving cognition and related brain function.

The purpose of this study was to investigate the effect of caffeine on brain function, and namely, more detail effect of caffeine on *short-term memory*. We used electroencephalography (EEG) measurements to check the participant performing a short-term memory task before and after having caffeine. We analyzed brain activity in the Delta, High Alpha and Low Beta band, which is suggested to be related to concentration.

2. MATERIALS AND METHODS

2.1 Participants

One healthy male participant (the author of this paper), 22 years old, with normal vision participated in the experiments. The participant did not have any history of neurological, psychiatric or vascular illness (disease), no history of alcohol or drug abuse and the participant is non-smoker. The participant reported that he is a low-level caffeine consumer (consumption is lower than 75mg/day, Nehlig, 2010). (For our future research, we plan to recruit more subjects, but the recruitment will need a special administration permission.)

2.2 Stimuli

A commercially available caffeinated drink was used for the test ("Boss Coffee Café au Lait"), which contains 140mg of caffeine. The participant took coffee four different times in a day: morning (6am to 9am), lunch (12pm to 5pm), dinner (5pm to 9pm) and night (9pm to 11pm).

2.3 Experimental Task 1

Memory (especially, memorizing numbers, languages, and learning figures) is a cognitive function closely related to everyday life skills. Memory impairment is one of the most important symptoms in patients with dementia and brain damage and it is also one of the most commonly reported cognitive symptoms in psychiatric clinic such as depression and anxiety. Recently, minor impairment of working memory occupies an important position in the study of pathophysiology such as schizophrenia and is newly emerging as an element of cognitive rehabilitation. For this reason, several simple memory tests have been developed and used in clinical trials to evaluate various memory impairments in various neuropsychiatric disorders.

Memory assessments used in clinical practice can be classified into immediate and short-term memory and long-term memory evaluation. On the other hand, they can be divided into verbal memory, spatiotemporal memory, and behavioral memory. Since long-term memory is often influenced by the life history of each subject, it is true that it is not easy to develop a standard tool and apply it to the clinic. Therefore, in practice, a standardized language and spatiotemporal stimulus is presented, and methods for immediately evaluating memory ability, memory registration, retention and retrieval, and learning ability are mainly used.

In this study, the results were computerized through tests that have been verified for reliability and validity. In addition to the visualization of the stimulus, standardized feasibility, ease of interpretation of the results, and computerization, the overall test execution time and comprehensive evaluation of various memories were considered. Therefore, in this study digit span and visual span (**Corsi block-tapping test**) has been used.

According to neuroscience and psychology studies, it is known that the longest list of items that a person can repeat back (which means memory span) in right order, is only 50% right after all presentation. For the items, numbers, words or pictures can be included. When we used the numbers for these tasks, we call it as digit span. Overall, memory span is known as a common measurement of short-term memory. It is also known as a component of cognitive ability test. Backward memory span is a more difficult work, it makes participant to recall the memorized items in reverse order.

2.3.1 Digit Span

A digit span task is known to use for measuring capacity of humans working memory number storage. Participants must memorize what they have seen or heard as a list of numerical digits and it is asked to recall the numbers correctly, with increasing longer digits being tested in each trial. The participant's span is the longest number of digits that can they have been remembered. Digit span tasks can be given forwards or backwards, which means that when the numbers are shown, the participant should recall the numbers in normal or reverse order. As it was written above, digit span tasks are the common tests for memory span, because performance of memorizing the numbers (digit span test) is hard to be affected by other factors.

A digit-span test has been done with three forward sets of 3- to 8-digit numbers and three backward sets of 3- to 7-digit numbers. The performance of the test was followed by the general numerical method. The number has been shown with intervals of 1 second, after all the numbers are shown participant is required to press the number in the order. For the backward digit test number should be listed in backward order. The same number of digits was checked three times, and if the numbers were wrong three times sequentially, the test was terminated. The result is that the maximum number of correctly remembered digits and the number of correctly answered digits are displayed as 1/3, 2/3, 3/3, etc.

2.3.2 Visual Span

The Corsi block-tapping test is another way to measure short-term working memory. Comparing with the above digit span method, the Corsi block-tapping test is related to mimicking (repeating) the sequence of nine separated blocks. The sequence starts simply, same as digit span test, and become more difficult and complex until the participant cannot get the correct order.

In this study, Corsi block-tapping test has been set as follows: maximum nine blocks on the screen where blocks appeared in a random place. After a certain number of blocks has been shown, the subject was asked to click on the blocks with the mouse in order. The stimuli were presented in the same way and order as used in digit span. After the forward test, the backward test was performed in the same way.

2.4 Test-Retest Reliability and Validity Verification

After the retest, paired t-test and Pearson correlation coefficients were calculated for each scoring item to verify test-retest reliability. The result of tests and retests are shown below.

Table 1. Paired t-test and Pearson correlation between test and retest scores (N=30).

Test / variables	Test scores	Retest scores	T (df =29)	Pearson
Digit span				
Forward	7.73 ± 0.24	7.75 ± 0.23	0.7	0.09
Backward	6.83 ± 0.17	6.85 ± 0.17	0.6	0.06
Visual span				
Forward	7.88 ± 0.17	7.86 ± 0.17	0.8	-0.05
Backward	6.86 ± 019	6.82 ± 0.21	0.38	0.06

When we just check the scores only, it seems that there are no differences in scores between all tests and retests. To check the procedure more correctly, we used the results of t-test and Pearson correlation. For the t-test, statistical significance was verified based on p = 0.05. All the p-values of digit span (forward & backward) and visual span (forward & backward) were bigger than 0.05 (see Table 1.). Therefore, we could conclude that there is no significant difference between the test and retest scores. For the Pearson's correlation, all the output values are close to 0, which means there is no linear correlation between the test and retest. Therefore, we could say the test that we used in this project is reliable.

2.5 EEG (Electroencephalogram / Electroencephalography)

An electrical (electro-) signal generated by nerve activity in the brain (encephal-) is recorded in the cerebral cortex or scalp, or its description (-gram /-graphy), also called electroencephalography (EEG). It's the simplest way to measure brain activity, and it has many uses, from medical use in epilepsy and diagnosis of dementia to interface technology. Also, magnetic field changes occur in the brain due to neural activity represented by electrical signals. The magnetic field recording is called magnetoencephalography (MEG).

2.5.1 Types of Brain Waves

Basically, five kinds of brain waves are known. Start with a low frequency band. Delta Wave is a brain wave with 0-4Hz. In general, it is a brain waves comes from sleep states, this signal is coming from all over the brain. The amplitude is very high compared to low frequencies. Because the frequency band is close to 0Hz, the band is directly affected by the DC component, so it is often removed by filtering when measuring brain waves except sleep brain waves. The frequency band affected by human movement or other noise during measurement. Theta waves are brain waves with 4-8Hz. These waves come from hypnosis and drowsiness states. Strangely, Theta waves are active in rodent-like species. In humans, Alpha and Beta waves are mainly active. Theta signal usually occurs in the hippocampus and hypothalamus of the brain structure. Which means it occurs in the mammalian brain. Medically, it occurs more often in children and infancy than adults. Alpha wave is a brain wave with 8-12Hz. If Delta waves and Theta waves are brain waves coming out when human beings are in non-awakening states, it can be said that waves started from Alpha waves, are brain waves of an awakening state. This wave is specific for arousal state, and especially noticeable when the eyes are closed. Because of this, it is closely related to the visual field. Beta wave refers to the brain wave within the range of 15 ~ 30Hz. Among the brain waves in the arousal state, the brain waves occurred during daily cognitive and thinking activities are the most powerful brain waves. Compared to the Delta wave, the amplitude itself is low, while it has high frequency, and it is sub-divided into Beta 1, Beta 2, and Beta 3 according to the frequency band. Gamma wave is a brain wave with a frequency above 30 Hz. It is a high frequency brain wave that comes from an extremely nervous or excited state. Since Gamma waves are difficult to measure and maintain by EEG sensory devices, studies of Gamma waves were not actively conducted. Therefore, the brainwaves investigated most deeply, were SMR waves in the range from 12 to 15 Hz.

2.5.2 SMR (Sensory Motor Rhythm) Wave

The center frequency is 12.7Hz, and it is a fast brain wave in the range of 12 ~ 15Hz, which is a kind of very important brain wave recently discovered. It appears mainly in passive brain activity, which predominantly occurs in the cerebral neocortex, from the ear down to the center of the brain. It appears when solving problems that require simple concentration.

In the state of consciousness, it appears on demand for relaxation. In other words, you can concentrate without nervousness and accurately without being stressed.

The above-mentioned brain wave properties are summarized in Table 2.

Table 2. Brain waves.

Frequency	Wave	State
30Hz ~	Gamma	Nervousness, anxiety
15 ~ 30Hz	Beta	Concentration
12 ~ 15Hz	SMR	Concentration (low stress)
8 ~ 12Hz	Alpha	Meditation
4 ~ 8Hz	Theta	Sleepy, distracted
0 ~ 4Hz	Delta	Sleep

2.5.3 EEG Sensor

For measuring brain waves, we used NeuroSky MindWave Mobile 2. According to the device website specification (NeuroSky, 2020), the MindWave Mobile 2 measures and outputs of the EEG power spectrums (for Alpha, Beta, Gamma waves) with their own sensor NeuroSky eSense measurement units (which can show scores from 0 to 100 for attention and meditation) and eye blinks. The device is consisted with a headset, ear clip and sensor arm. The headset's reference and ground electrodes are placed on the ear clip and the electrode, for sensing the EEG, is on the sensor arm, where it is on the forehead above the eye. With the usage of a single AAA battery, it can be run 8 hours. In detail, MindWave Mobile 2 uses the TGAM1 module, with automatic wireless pairing. It requires a single AAA battery for 8-hours run time, and BT/BLE dual mode module (10 meters range) is used. It measures 12-bit raw brain waves (3 ~ 100Hz) with sampling rate at 512Hz. Outputs of the device are EEG power spectrums, and EEG/ECG signal quality analysis data. The sensors used by NeuroSky MindWave headset do not require gel or saline for recording, and no expertise is required for setup.

2.6 Experimental Task 2

Hypothesis. When the participant completes span tests (similar to the performed for Experimental Task 1), the attention level (recorded by the NeuroSky MindWave mobile 2) is expected to correlate with the result of the span test. The attention level was calculated by output value of High Alpha, Low Beta and Delta signals. This study hypothesizes that there is positive correlation between attention level and the test scores. Moreover, as we check the results of the span test after consuming caffeine, it was also possible to obtain the correlation between the caffeine concentration, and the time moment when caffeine effects are most significant.

The experiments were conducted similar to Experimental Task 1. The only difference is that as we need to compare the difference between two states, the span tests also have been recorded two times: before consuming caffeine and 30 minutes after taking caffeine. Also, as you can see from the results of Experimental Task 1 (without having caffeine), the scores that the participant got are close to the perfect scores. Therefore, for Experimental Task 2, we decided to increase the digit number for the span test. The resulting data were recorded similarly to Experimental Task 1: the maximum number of correctly remembered digits and the number of correctly answered digits.

3. RESULTS AND DISCUSSION

The results of the experiment were what we expected. The following figures show the results of EEG data while doing span tests in two states before caffeine consumption and 30 minutes after caffeine intake.

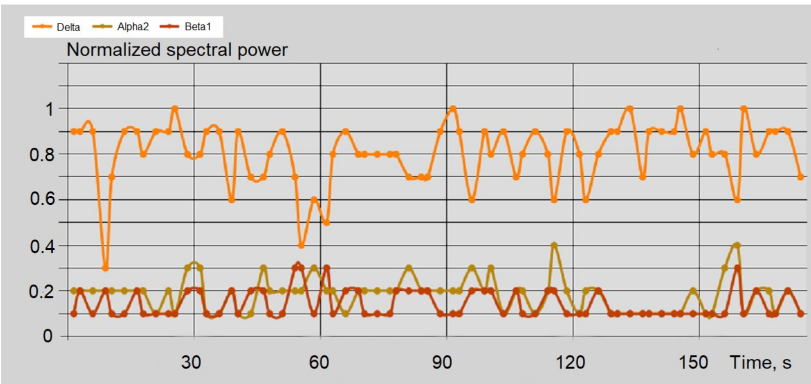

Fig. 1. Real time brain wave graphs (Delta, Alpha and Beta) before caffeine intake

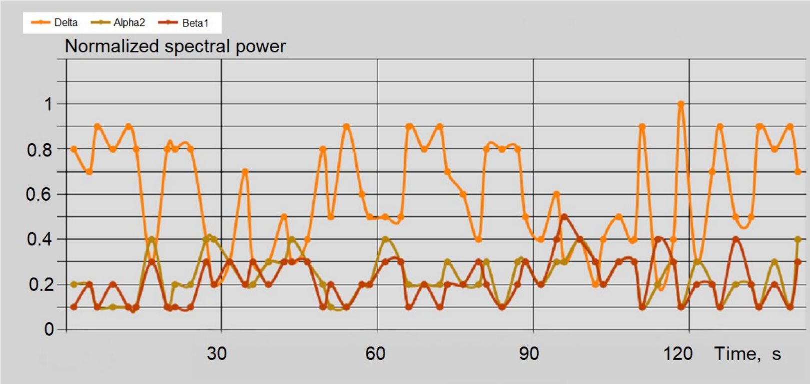

Fig. 2. Real time brain wave graphs (Delta, Alpha and Beta) 30min after having caffeine intake

Looking at Figure 1 and Figure 2 we can see a variety of results. The first thing we noticed is the change in brain waves. As we expected, when the participant was focused on the experiments, the Delta value has been decreased, while Alpha and Beta values have risen above the previous value. The state before caffeine intake shows a calm graph with little change in Alpha and Beta values. In contrast, the graph after ingesting caffeine shows that the Alpha and Beta values were changed significantly. Even though we consider the high Delta amplitude, the change in value before and after caffeine is noticeable. In order to easily identify the difference between the three EEG values, the average value is shown as a bar graph.

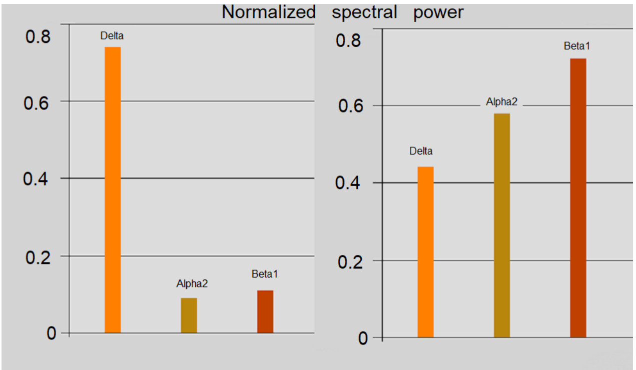

Fig. 3. Average value before (left) and 30 min after caffeine intake (right)

As shown in Figure 3, before caffeine intake each value was as follows. Delta, Alpha, and Beta were 0.76, 0.1, and 0.11, respectively. In contrast, after 30min after taking caffeine the values were as 0.21, 0.29, and 0.35. Nearly a quarter of the difference in Delta values and more than three times the difference between Alpha and Beta is shown.

As mentioned in the first part of this paper, four different time periods were used to compare the data before and after caffeine intake. As we used the simple span tests, it was hard to find differences in scores. Even in terms of the EEG strain, it was difficult to distinguish the difference of the strain values for four different time periods. After taking caffeine, the level of concentration was better than before, but the change in rise at the same time period was different. It was hard to confirm the expectation that the score would be higher as the concentration level increased because it was difficult to compare the score differences. However, as the concentration level increased, the participant felt that it was less difficult to remember in the span test.

4. CONCLUSION

Through this study, it was confirmed that the caffeine intake showed a higher concentration level than before ingestion. However, it is very difficult to find the correlation between the levels of concentration and the scores. In the future research improvements, we need to increase the number of the samples for the experiment. To confirm the increase of the scores according to the increase of concentration through experiments, it will be useful to invent a new test system (based on new sensory devices, applications, and experimentation plan). As for expected scenarios, a real-time concentration check application can be created to help the subjects/experimenters to check this score-concentration dependency. However, excessive experimental work puts a strain on the subject body and slows down his/her work. Therefore, it is expected that the proper rest through the application working session will be provided.

REFERENCES

Blanchard, J., and Sawers, S.J.A. (1983). The Absolute Bioavailability of Caffeine. *Man. Eur. J. Clin. Pharmacol.*, 24, 93–98.

Brice, C.F., and Smith, A.P. (2002). Effects of caffeine on mood and performance: a study of realistic consumption. *Psychopharmacology*, 164, 188–192.

Brunyé, T.T., Mahoney, C.R., Lieberman, H.R., and Taylor, H.A. (2010). Caffeine modulates attention network function. *Brain Cogn.*, 72, 181–188.

Einother, S.J.L., and Giesbrecht, T. (2013). Caffeine as an attention enhancer: Reviewing existing assumptions. *Psychopharmacology*, 225, 251–274.

Haskell, C.F., Kennedy, D.O., Wesnes, K.A., and Scholey, A.B. (2005). Cognitive and mood improvements of caffeine in habitual consumers and habitual non-consumers of caffeine. *Psychopharmacology*, 179, 813–825.

Lieberman, H.R., Wurtman, R.J., Emde, G.G., Roberts, C., and Coviella, I.L. (1987). The effects of low doses of caffeine on human performance and mood. *Psychopharmacology*, 92, 308–312.

Nehlig, A. (1999). Are we dependent upon coffee and caffeine? A review on human and animal data. *Neurosci. Biobehav. Rev.*, 23, 563–576.

Nehlig, A. (2010). Is caffeine a cognitive enhancer? *J. Alzheimers Dis*., 20, S85–S94.

NeuroSky. (2020). http://neurosky.com (last accessed on March 13, 2020).

Ramakrishnan, S., Laxminarayan, S., Wesensten, N.J., Kamimori, G.H., Balkin, T.J., and Reitman, J. (2014). Dose-dependent model of caffeine effects on human vigilance during total sleep deprivation. *J. Theor. Biol.*, 358, 11–24.

Van Dongen, H.P.A., Price, N.J., Mullington, J.M., Szuba, M.P., Kapoor, S.C., and Dinges, D.F. (2001). Caffeine eliminates psychomotor vigilance deficits from sleep inertia. *Sleep*, 24, 813–819.

Van Duinen, H., Lorist, M.M., and Zijdewind, I. (2005). The effect of caffeine on cognitive task performance and motor fatigue. *Psychopharmacology*, 180, 539–547.