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Accessing the Impact of Caffeine on Stress and Cognitive Attention

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Abstract. Caffeine is the most widely consumed drug in the world and affects people's mental and physical health. This paper utilizes photoplethysmographic (PPG) and Galvanic Skin Response (GSR) sensors to assess the stress level, attention, and heart rate responses triggered by caffeine. The experiment was conducted in one day with 12 middle-aged participants (ages 26 to 46), and a stress level questionnaire was used to record stress scores. The sensor results showed that both the average heart rate per minute and stress level increased. Although the differences in stress scores based on the questionnaire before and after drinking coffee were not significant, the majority of participants presented higher accuracy scores in the PASTA test after drinking coffee.

Keywords: coffee, pressure, attention, photoplethysmographic (PPG) and Galvanic Skin Response (GSR), heart rate

1. Introduction

Caffeine, a popular ingested pharmacologically active substance, is consumed by people throughout the world. This widespread substance comes from natural plants and appears in people's lives frequently, especially in beverages such as coffee [1]. Drinking coffee contributes to energetic and therapeutic effects and may even reduce the risk of Parkinson's and Alzheimer's diseases [2]. However, taking too much caffeine may cause many clinical symptoms, ranging from nervousness, irritability, and insomnia to physical impacts such as arrhythmia [3]. According to research in the mental health area, whether caffeine is beneficial to stress levels and attention is still a topic of debate. A paper written by James et al [4]. reported that intake of caffeine may not affect the stress level of psychiatric in-patients, but one paper by Bruce [5] pointed out that caffeine might raise the stress level for those with anxiety disorder. This paper designs an experiment using PPG and GSR to measure the general people's heart rate, stress level, and attention before and after drinking coffee, especially focusing on middle-aged people. 12 participants, including 10 women and 2 men took part in this experiment. The stress level questionnaire and the PASTA test were used to help investigate the stress and attention.

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2. Literature review

2.1. The principle of PPG

This experiment uses a photoplethysmographic (PPG) sensor to detect heart rate. PPG measures the change of blood volume in the microvascular bed of the tissue by using light detection [6]. This sensor consists of a detector and red or infrared light-emitting diodes as the light source. Light is absorbed by biological tissue such as skin and venous blood, and PPG measures changes in light intensity caused by blood perfusion through the tissues. A change in the intensity of light can reflect on people's cardiovascular system, respiratory, and nervous system. Different wavelengths of light penetrate the skin to different depths. Green light suits the superficial blood flow in the skin, while red and infrared light are better in the deep tissue. However, PPG has several limitations, as the detected light intensity can be affected by blood volume, red blood cell orientation, vessel wall movements, and motion artifacts [7].

There are two types of PPG: transmission and reflectance (Fig.1). Transmission mode has to be placed in sites that are easy to detect light, such as the fingertip and earlobe. This mode is beneficial to obtain a good quality of signal, although there are limitations for the measurement places and are easily influenced by environmental factors. For the reflectance mode, reflected light from tissue or blood vessels is detected. It has various sensor placements, while motions and pressure disturbances affect the accuracy of the sensor. Transmission mode is usually used in clinical systems, such as a clip attached to the index finger to measure blood oxygen, and reflectance type is used in the majority of wearable devices [7].

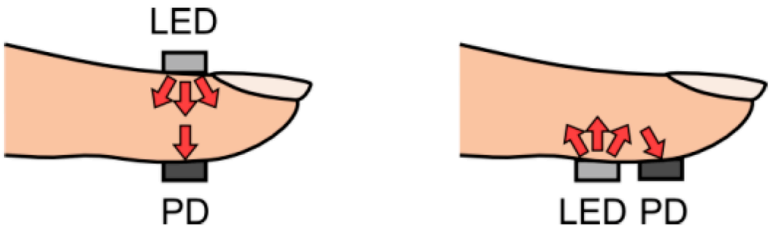

Figure 1. Two modes for PPG-- transmission and reflectance with light-emitting diode and photodetector [6]

PPG sensors can be applied in many medical applications. There are two approaches: contact and non-contact PPG, which are used to measure pulse rate (PR) and pulse rate variability (PRV). Additionally, blood oxygen saturation and blood pressure can be continuously monitored by placing sensors on the earlobe or using a wrist-worn band. Furthermore, respiratory rate (RR), arterial stiffness, aging, and even the autonomic nervous system can be assessed to prevent diseases in advance [8].

2.2. The principle of GSR

The GSR sensor is used to determine a human's emotional state by using two electrodes. This sensor measures the electrical conductivity of the skin. When people feel anxious, fearful, or ecstatic, their nervous system is stimulated, leading to increased sweat production. The sensor operates based on the principle of electrodermal activity (EDA), where skin resistance varies with the state of the sweat glands [9]. When sweat gland activity is higher, skin conductance increases, resulting in lower resistance.

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3. Methodology

This study involves 12 participants of different ages, ranging from 26 to 46. The PASTA test is used, in which participants need to sum up the last 3 numbers during the test. PPG and GSR sensors are placed on the fingers and used to identify their heart rate and skin conductance. The test is conducted within a single day, and the two testing sessions are separated by more than 8 hours, as mood does not change significantly within a short period, as shown in Figure 2.

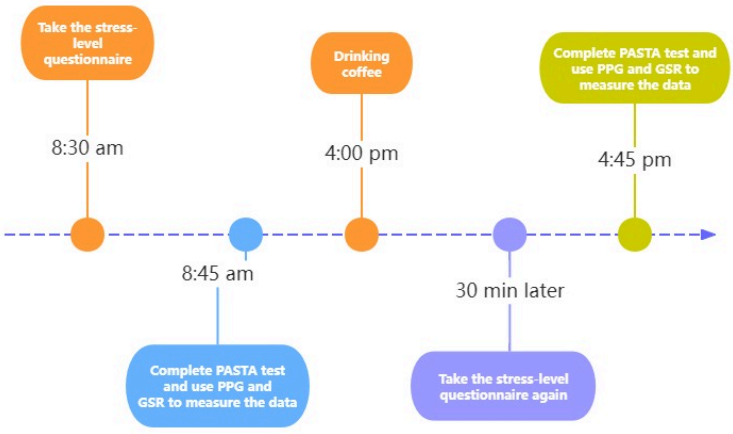

Figure 2. The overall process of the experiment

The participants were required to complete a stress level questionnaire in the morning and take the PASTA test. The questions were chosen from the Perceived Stress Scale (Fig.3). However, the questions were modified by changing “in the last month” to “recently” in order to narrow the range and obtain more accurate stress feedback (Fig.4).

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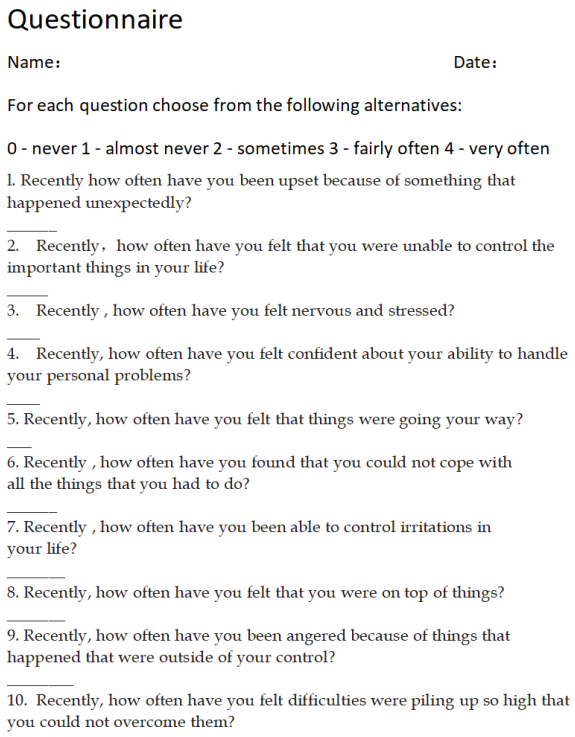


Questionnaire

Name: Date:

For each question choose from the following alternatives:

0 - never 1 - almost never 2 - sometimes 3 - fairly often 4 - very often

l. Recently how often have you been upset because of something that happened unexpectedly?

_____

2. Recently, how often have you felt that you were unable to control the important things in your life?

_____

3. Recently , how often have you felt nervous and stressed?

____

4. Recently, how often have you felt confident about your ability to handle your personal problems?

____

5. Recently, how often have you felt that things were going your way?

___

6. Recently , how often have you found that you could not cope with all the things that you had to do?

_____

7. Recently , how often have you been able to control irritations in your life?

_____

8. Recently, how often have you felt that you were on top of things?

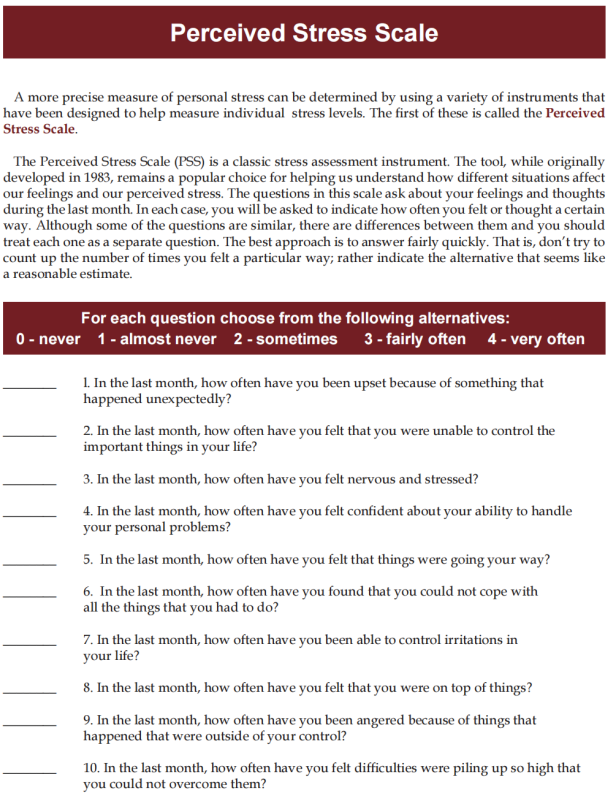
_____

9. Recently, how often have you been angered because of things that happened that were outside of your control?

_____

10. Recently, how often have you felt difficulties were piling up so high that you could not overcome them?

Figure 3. Perceived stress scale



Perceived Stress Scale

A more precise measure of personal stress can be determined by using a variety of instruments that have been designed to help measure individual stress levels. The first of these is called the Perceived Stress Scale.

The Perceived Stress Scale (PSS) is a classic stress assessment instrument. The tool, while originally developed in 1983, remains a popular choice for helping us understand how different situations affect our feelings and our perceived stress. The questions in this scale ask about your feelings and thoughts during the last month. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between them and you should treat each one as a separate question. The best approach is to answer fairly quickly. That is, don't try to count up the number of times you felt a particular way; rather indicate the alternative that seems like a reasonable estimate.

For each question choose from the following alternatives:
0 - never 1 - almost never 2 - sometimes 3 - fairly often 4 - very often

_____ l. In the last month, how often have you been upset because of something that happened unexpectedly?

_____ 2. In the last month, how often have you felt that you were unable to control the important things in your life?

_____ 3. In the last month, how often have you felt nervous and stressed?

_____ 4. In the last month, how often have you felt confident about your ability to handle your personal problems?

_____ 5. In the last month, how often have you felt that things were going your way?

_____ 6. In the last month, how often have you found that you could not cope with all the things that you had to do?

_____ 7. In the last month, how often have you been able to control irritations in your life?

_____ 8. In the last month, how often have you felt that you were on top of things?

_____ 9. In the last month, how often have you been angered because of things that happened that were outside of your control?

_____ 10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?

Figure 4. The new stress-level questionnaire

At dinner time, participants drink a cup of coffee and take the PASTA test 30 minutes later, when the effect of caffeine on the human body reaches its peak. The same stress-level questionnaire is used to measure the stress again, and two sets of data are compared. A higher GSR value means a high skin conductance. In these cases, such data present a higher stress level. BPM (beats per minute) is calculated by measuring the number of wave peaks in one minute. Heart rate increases as the value of BPM rises.

4. Results

The BPM of participants (Fig.5) after drinking coffee (Median (M) = 92.91, Standard Deviation (SD) = 9.98) was higher compared to that of participants who did not drink coffee (M = 81.29, SD = 6.51). This indicates that the average heart rate increased following caffeine intake. Additionally, the GSR values (Fig.6) after drinking coffee (M = 445.23, SD = 103.27) were compared with those without drinking coffee (M = 433.70, SD = 91.83).

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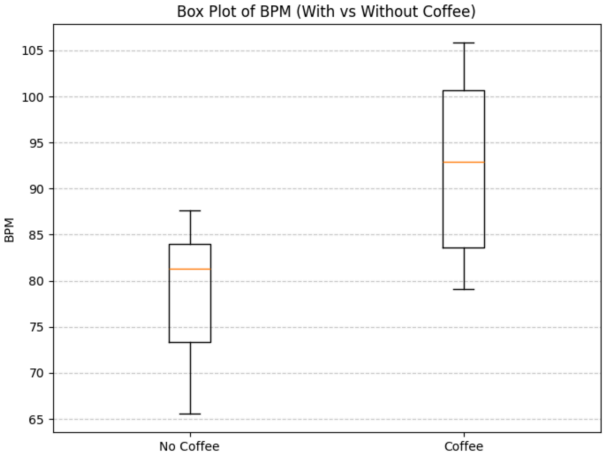

Figure 5. The box plot of BPM

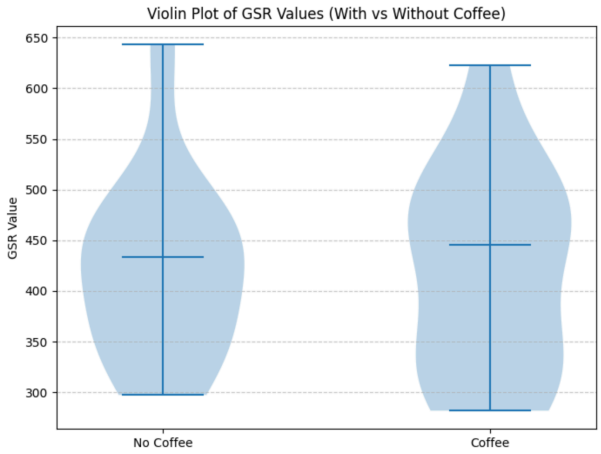

Figure 6. The plot of GSR value

The comparison of stress level scores is shown in Fig.7. The average stress score with drinking coffee was 19.9 compared to that without coffee (18.6). The majority of participants demonstrated an increase in stress level scores after drinking coffee, although the changes were not dramatic.

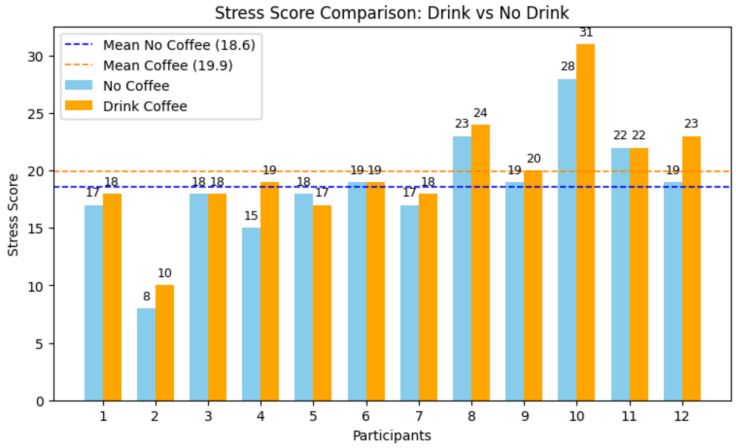

Figure 7. The bar chart of stress score comparison

The accuracy of the PASTA test is presented in Table 1. More than half of the participants showed improved test scores after drinking coffee. The average PASTA score was 68.8 without coffee, and it increased to 75.7 after coffee consumption.

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Table 1. The participants' scores on the PASTA test

Participant	Accuracy (No Coffee) (%)	Accuracy (Coffee) (%)
1	62.0	77.0
2	62.0	62.0
3	62.0	54.0
4	69.0	85.0
5	85.0	77.0
6	69.0	69.0
7	100.0	100.0
8	69.0	69.0
9	54.0	92.0
10	54.0	69.0
11	85.0	85.0
12	54.0	69.0
Average	68.8	75.7

5. Data analysis

According to Fig.5, the median value of BPM increases after drinking coffee. Compared with the mean, the median is less influenced by extreme values. Notably, the median BPM after coffee intake (92.91 BPM) exceeded the maximum BPM recorded in the no-coffee condition, indicating that more than half of the participants had higher heart rates post-caffeine than the highest non-caffeine value. In this case, coffee raised BPM for the majority of people rather than the increase being caused by specific high values. Furthermore, the standard deviation reflects the degree of dispersion of the data, that is, how much difference there is between individuals and the mean. The increase in SD after caffeine intake indicates that while the overall BPM goes up, some people may not have a significant increase in their heart rate, or even have about the same rate as when they didn't drink. The differences between BPM after drinking coffee are associated with personal constitution. People who often drink coffee may develop resistance to the effects of caffeine, whereas non-habitual drinkers are less likely to exhibit such resistance.

As can be seen from Fig.6, both the maximum and minimum values of GSR decreased compared to the condition without drinking coffee, although the median GSR (after drinking coffee) showed an increase. More specifically, after drinking coffee, the GSR values of more participants were above approximately 550, and the maximum and minimum values were about 10 units lower than those in the no-coffee condition. This indicates that most participants experienced an increase in GSR, while some individuals demonstrated decreases. The standard deviation after drinking coffee is greater, which indicates that not everyone became more nervous. Besides, the GSR values may be affected by the environmental factors, including ambient temperature and individual physiological differences such as skin condition.

Based on the Fig.7, 8 participants showed an increase in stress level scores, 3 participants showed no change, and 1 participant showed a decrease. The average stress score after drinking coffee was 1.3 points higher than that without coffee. However, this difference is not significant, since the questionnaire had to be completed twice in one day. Participants may not have shown obvious

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changes in mood, and some individuals may even have remembered the answers they provided in the morning. Nevertheless, most stress scores in the evening differed from those in the morning, and events that occurred during the day may also have influenced the scores. Therefore, considering both the physiological GSR values and the increase in average stress scores, the results indicate that drinking coffee can make people feel more nervous and suggest a positive relationship between caffeine intake and stress.

From Table 1, the average accuracy score increased by 6.9 points after drinking coffee, which demonstrates that it is beneficial to attention after caffeine intake. Although the overall scores were enhanced, not everyone benefited. Participants 2, 6, 7, 8, and 11 showed no change in accuracy, and the scores decreased slightly for Participants 3 and 5 (−8%). Additionally, Participant 7 remained at 100% in both cases, indicating that caffeine had little effect on him. The data show that the effects caused by caffeine depend on personal conditions. Some people may become more focused, while others may feel they cannot pay attention. Based on the information from Table.1 and Fig.7, it can be seen that stress levels have a positive relationship with attention: when people feel more stressed, their attention tends to increase, and they perform better in the test. One of the factors influencing the accuracy of results is the potential learning effect: participants who completed the test without coffee did it for the first time, but when taking it again after drinking coffee, they might have become more familiar with the task and applied improved strategies.

6. Conclusion

The study analyzed the principles of PPG and GSR sensors and presented different types of PPG sensors, along with their respective limitations. Caffeine increased stress levels and elevated heart rate in the majority of participants, based on the analysis of PPG and GSR values. Moreover, the average questionnaire stress score after drinking coffee was slightly higher than without coffee, suggesting greater perceived stress. In addition, drinking coffee appeared to improve attention for some people, but the effect was not significant since it depends on personal conditions, as reflected in the higher accuracy of test scores.

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