Wearable-Based Detection of Caffeine-Induced Physiological Changes and Concentration in High School Students

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Overview: we investigate whether a moderate amount of caffeine intake can have significant impacts on high school students' concentration by collecting data via wearable sensors

Introduction

Caffeine is the most consumed psychoactive stimulant among high school students, often used to combat academic fatigue and enhance focus.

While adult studies link caffeine to increased alertness, elevated heart rate, and reduced HRV, adolescent-specific real-world data remain scarce.

One major limitation in currently existing research on the intake of caffeine in the population of high school students or adolescents is the significant inclusion on self-reported data on caffeine intake while following with subjective evaluations on concepts such as focus, stress, and sleep quality. Although these methods do provide important conceptual data, they often lack in objectivity and consistency that are needed to fully understand the physiological effects of caffeine intake. Nonetheless, only few studies have applied such methods to adolescent populations.

Results

Across participants, PPG amplitude decreased by an average of 14.2% post-caffeine ($p$adj < 0.001; paired-samples t-test), consistent with vasoconstriction. GSR responses showed a mean increase of 6.8% in conductance (p = 0.041; paired samples t-test), while BPM changes were heterogeneous with no significant group-level shift (p = 0.37; paired-samples t-test). HRV (RMSSD) decreased by 7.4% (p = 0.018; paired samples t-test), aligning with increased cognitive engagement.

Table 1 summarizes the mean values (±SEM) for BPM, PPG, and GSR across participants before and after caffeine intake. In contrast, PPG amplitude demonstrated a marked and consistent decrease following caffeine consumption, consistent with the expected peripheral vasoconstriction effect. GSR exhibited mixed responses across the cohort, with some participants showing an increase and others a decrease.

TABLE I
PAIRED-SAMPLE t-TEST RESULTS FOR PHYSIOLOGICAL MEASURES.

Measure	Mean Diff	$t(29)$	p_{adj}
BPM	+1.1	1.12	0.273
PPG	−129.2	-5.94	< 0.001
GSR	+1.4	0.84	0.408

Table 1. Paired-sample t-test results showing a significant reduction in PPG amplitude after caffeine ingestion (padj < 0.001), with no significant changes observed for BPM or GSR.

Paired-sample t-tests were conducted to compare heart rate (BPM), photoplethysmography amplitude (PPG), and galvanic skin response (GSR) before and after caffeine intake.

Caffeine ingestion led to a significant reduction in PPG amplitude (padj < 0.001), indicating peripheral vasoconstriction. No statistically significant group-level changes were observed for BPM or GSR.

Methods

Figure 1. Example of the experimental setup, showing a participant completing the focus test while connected to wearable physiological sensors.

This study uses a within-subjects design, where each participant completes a standardized focus assessment before and after consuming a serving of coffee. This design allows for paired comparisons of focus scores, controlling for inter-individual variability and increasing statistical sensitivity to changes brought on by caffeine intake.

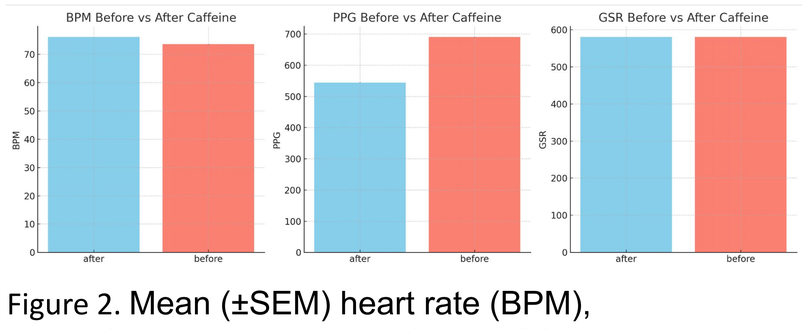

Figure 2. Mean (±SEM) heart rate (BPM), photoplethysmography amplitude (PPG), and galvanic skin response (GSR) before and after caffeine ingestion

Thirty participants (15M, 15F) from three different high schools participated. Each consumed a single serving of black coffee containing 180–210 mg caffeine, followed by a 20-minute absorption period before testing. Tests included a color word task and a repeated letter matching task, administered via TotalBrain.com.

To examine how caffeine intake affects the focus of adolescents and cognitive participation, participants completed a standardized digital focus test before and after consuming a single serving of coffee (180mg-210mg). One part of the test resembled a Stroop task, in which participants were shown words that represented colors (such as 'red'' or 'blue') printed in a font color that may or may not match the meaning of the word. Another component of the test involved a working memory task in which a series of letters appear one at a time, and participants were instructed to click only when the same letter appeared consecutively.

PPG signals were collected by wearable PPG sensors worn on the earlobe (sampling rate: 100 Hz). GSR and skin temperature were recorded with a GSR sensor on the index and middle fingers.

During each test session, physiological signals were continuously recorded using two types of wearable sensors to capture real-time responses related to mental effort and alertness. Photoplethysmography (PPG), positioned in the earlobe, mon- itored heart rate and heart rate variability (HRV) by measuring changes in blood volume in the microvascular bed of tissue [11]. The galvanic skin response (GSR), attached to the index and middle fingers, recorded changes in skin conductance, which reflects the activity of the sweat glands triggered by emotional or cognitive arousal.

Conclusion

Moderate caffeine intake (180–210 mg) can acutely in fluence multiple physiological markers associated with concentration in high school students. In particular, consistent vascular effects were observed through reductions in PPG amplitude, while changes in BPM and GSR exhibited notable individual variability. These findings suggest that caffeine's impact on cardiovascular and electrodermal activity is both measurable and subject-specific.

This study investigated the acute effects of caffeine consumption on physiological and behavioral markers of academic concentration in high school students, using a within-subjects design and wearable sensor data from 30 participants. By combining objective biometric measurements—photoplethysmography (PPG), galvanic skin response (GSR), and beat-to-beat heart rate variability (HRV)—with standardized cognitive testing, the research addressed a key gap in high school caffeine studies, which have historically relied heavily on self-reported measures or adult-based laboratory data.

References & Acknowledgements

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