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The Effect of Caffeinated Chewing Gum on the Levels of VO_2 Max among Physically Active Individuals

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ABSTRACT

Background: Caffeine is one of the most popular ergogenic aids widely used by coaches and athletes. Caffeinated chewing gums can be rapidly absorbed and may improve endurance as measured by VO_2 max. This study investigates the effect of caffeinated chewing gum on the levels of VO_2 max among physically active individuals. **Methods:** A randomized, double-blind, placebo-controlled, matched-pair trial design was used. Twenty-two physically active men were recruited and completed this study. Participants were then divided into two groups: A caffeinated chewing gum group (CG) and a placebo group (PG), with eleven participants in each group. **Results:** No adverse effect was reported by the participants during this study. The findings showed that caffeinated chewing gum was not effective in improving right or left handgrip and back or leg dynamometer but effectively increased VO_2 Max (PG: 1.45±2.44 ml/kg vs CG: 4.14±2.12 ml/kg; P<0.012). **Conclusion:** This study concluded that a caffeine dose of ~180 mg or ~3 mg/kg body weight in chewing gum increases maximal oxygen uptake among physically active individuals.

Introduction

Maximal oxygen uptake (VO_2 max) is a quantitative measure of aerobic capacity and is recognized as one of the most reliable indicators of overall physical and cardiorespiratory fitness of an individual (Srivastava *et al.*, 2024). A higher VO_2 max is associated with greater aerobic capacity and endurance potential among athletes, which describes sport performance (van Der

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Zwaard *et al.*, 2021). A meta-analysis showed that high-intensity training significantly improves VO_2 max among elite athletes and promotes aerobic capacity (Ma *et al.*, 2023). Moreover, nutritional ergogenic aids, such as caffeine, beta-alanine, sodium bicarbonate, and sodium citrate, show a potential role in enhancing sport performance (Vicente-Salar *et al.*, 2022).

Caffeine is a common ergogenic aid for athletes. Numerous studies reported the effect of caffeine on metabolism, physiology, and performance (Guest *et al.*, 2021). Caffeine consumption improves isometric handgrip strength (Grgic, 2022) and lower-body muscular performance (Harty *et al.*, 2020). It can be administered through several forms, frequently as capsules, powders, and energy drinks, as well as chewing gum, nasal spray, and mouth rinses (Yang *et al.*, 2024). However, caffeine is effectively released up to 80% in the form of chewing gum within a short period of 5-10 minutes (Bellar *et al.*, 2011). For example, a low dose of caffeinated chewing gum (100-300 mg or 2-4 mg/kg) is quickly absorbed and utilized, thereby impacting performance (Yang *et al.*, 2024). Most studies have found that even with lower dosages of caffeine, pre-exercise supplementation of caffeinated chewing gum is effective in increasing lower limb strength, repeated-sprint ability, endurance, and sport-specific performance, as well as lowering the rating of perceived exertion (RPE) and fatigue index (Yang *et al.*, 2024).

Caffeine consumption can provide benefits in both the time to exhaustion and the maximal oxygen intake among active individuals. However, the effects of caffeine on VO_2 max tend to be more inconsistent and likely depend on an individual's tolerance levels and withdrawal durations from caffeine. Farmani *et al.* found that caffeinated chewing gum consumption for 10 minutes before exercise significantly increased table tennis players' performance, but there was no significant effect on VO_2 max (Farmani *et al.*, 2024). On the other hand, a meta-analysis of 32 studies showed that low doses of caffeine positively impact most exercise and physiological performance (Yang *et al.*, 2024). Nonetheless, limited studies have explored the effect of caffeine on VO_2 max. Therefore, this study aims to investigate the effect of caffeinated chewing gum on increasing VO_2 max among physically active individuals.

Materials and Methods

Design and participants

A double-blind, randomized placebo-controlled, matched-pair trial design was used to examine the effect of caffeinated chewing gum on strength and endurance performance among physically active students. Participants were pair-matched according to their baseline VO_2 max values, then randomly allocated into caffeine (CG) and placebo groups (PG) using a coin toss (**Figure 1**).

The sample size was calculated with G*Power 3.1 (Faul *et al.*, 2009). A sample size of 11 individuals per group was computed based on a significance threshold of 0.05 and a power (1-β) of 0.8. The inclusion criteria were as follows: Physically active male students aged 18-22 who engaged in training at least three times per week lasting about 1-2 hours. Volunteers who were caffeine-sensitive, unwell, or injured were excluded from this study using a generic pre-screening questionnaire. Eleven students were recruited and completed this study.

Procedures

Participants were instructed to maintain their regular food consumption, hydration, physical activity, and sleep patterns 48 hours before the testing sessions. They were provided with a journal to record the information throughout this study period. Participants were advised to engage in intense activity, avoid alcohol, and avoid caffeine consumption for 48 hours before the experiment. Food and activity data were reviewed to ensure compliance. Participants took part in three sessions at the Sport and Exercise Research Centre Hall, Universitas Negeri Surabaya (UNESA). The first session was a familiarization session without supplementation to help participants become accustomed to the testing procedures. Participants in the subsequent two sessions followed the same testing protocols but were given either caffeinated

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gum or placebo gum. All testing sessions were conducted at the same time of the day to control diurnal fluctuations. Prior to the familiarization experiment, body composition (HBF-375 digital scales, Karada scan, China), height (stature meter, GEA medical, Indonesia), blood glucose, cholesterol, uric acid (Easy Touch GCU, Taiwan), and hemoglobin (Easy Touch hemoglobin, Taiwan) were measured.

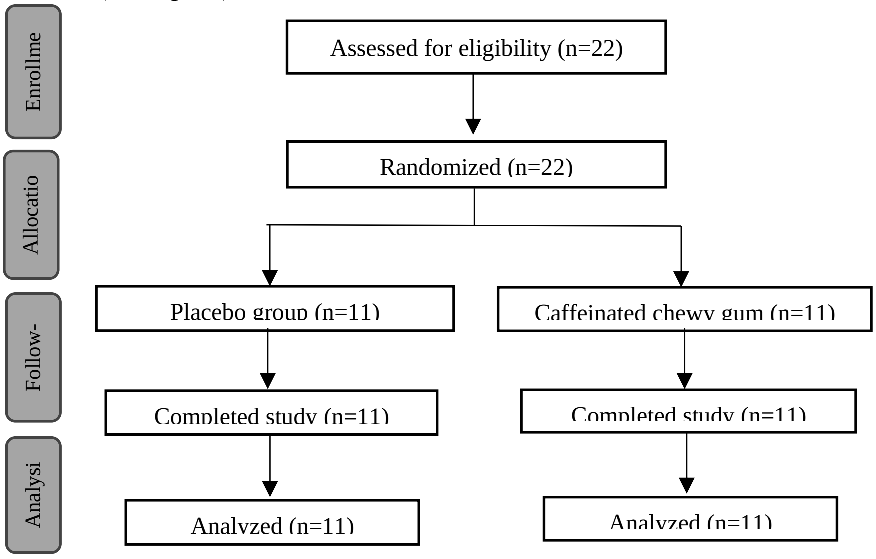

Figure 1. Flowchart of study

Caffeinated gum and placebo gum

The experimental gum was mocha-flavored and contained 15 mg of caffeine per piece. The placebo gum was identical in flavor and appearance but contained no caffeine. Participants were instructed to consume 12 pieces of gum (180 mg of caffeine, corresponding to 2.7±0.04 mg/kg body weight) for five minutes following the warm-up. Furthermore, chewing was timed by the researchers using a portable timer.

Strength and fitness test

Each participant provided a fingertip blood sample upon arrival. Random glucose, uric acid, and hemoglobin levels were measured using the Easy Touch GCU 3-in-1 device (MT Promedt Consulting GmBH, Germany) through a one-time blood sample (finger-prick) carried out by an enumerator. Handgrip strength was measured to the nearest 0.1 kg with a handgrip, back, and leg dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Participants stood with their arms lowered to the sides and their feet shoulder-width apart. They were instructed to grip the bar with their second finger and hold the dynamometer with each hand, back, and leg as hard as they could. Both sides were evaluated twice, with the highest values used.

Multiple fitness test (MFT)

The 20-meter MFT required participants to run back and forth between two lines set 20 meters apart at a pace determined by audio signals at fixed intervals (Dimarucot and Macapagal, 2021). The initial velocity was 8.5 km·h-1, increasing by 0.5 km·h-1 each minute thereafter. The participant's test score was determined by the total number of 20-meter shuttles completed before voluntarily withdrawing from the test or failing to reach within 3 meters of the end line on two consecutive audio cues.

Ethical considerations

This study obtained ethical approval from the Faculty of Dental Medicine and Health Research at Airlangga University (No. 1420/HRECC.FODM/XII/2023). All procedures conducted in this study were in accordance with the principles outlined in the Declaration of

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Helsinki. Prior to participation, all students completed a basic pre-screening questionnaire and signed a written informed consent form.

Data analysis

Repeated-measures ANOVA was used to assess the effect of the intervention on strength and endurance over time. Differences between groups (CG vs. PG) in strength and endurance were analyzed using an independent t-test, while within-group differences (pre- vs. post-intervention) were analyzed using a paired *t-test*. Statistical significance was set at $P<0.05$. All statistical and graphical analyses were performed using SPSS ver. 21 (IBM, Armonk, NY, USA).

Results

Side effects and effectiveness of blinding

No adverse effect was reported by the participants during this study. All participants were unable to distinguish between the caffeinated and placebo chewing gums because of their similar color and smell, which suggested that the blinding process was effective. At baseline, there were no statistical differences between the PG and CG in terms of age, height, weight, and body mass index (BMI) ($P>0.05$), except body fat (**Table 1**).

Table 1. Baseline characteristics of study participants.

Variable	Placebo (n = 11)	Caffeine (n = 11)	P-value[a]
Age (y)	19.64 ± 1.03[b]	19.55 ± 0.93	0.83
Height (cm)	165.27 ± 6.61	167.66 ± 5.57	0.37
Weight (kg)	65.39 ± 8.36	64.54 ± 7.56	0.804
Body mass index (kg/m^2)	23.64 ± 2.46	22.91 ± 2.03	0.458
Body fat (kg)	19.08 ± 3.28	15.20 ± 3.50	0.014
Visceral fat (kg)	6.77 ± 2.31	6.00 ± 1.75	0.386
Hemoglobin (g/dl)	15.78 ± 1.53	15.36 ± 1.09	0.469
Random glucose test (mg/dl)	94.18 ± 9.13	95.73 ± 9.52	0.702
Uric acid (mg/dl)	7.85 ± 1.13	9.30 ± 2.94	0.138

[a]: obtained from the independent t-test; [b]: Mean±SD.

The effect of caffeinated chewing gum on strength and endurance

Strength tests in this study included right-hand grip, left-hand grip, leg dynamometer, and back dynamometer. Endurance was evaluated using the MFT by measuring VO_2 max. Between-group analysis in the pre-intervention phase showed no differences in performance between the PG and CG in the strength tests, including right and left handgrip, leg and back dynamometer, and endurance, consisting of VO_2 max ($P>0.05$). Similar results were observed post-intervention with no differences in strength and endurance (**Table 2**).

To evaluate the time (pre- and post-intervention) and intervention effect on strength and endurance, a repeated-measures ANOVA was conducted (**Figures 2** and **3**). The results showed that caffeinated chewing gum was not effective in improving right-hand grip, left-hand grip, back dynamometer, or leg dynamometer, but effectively increased VO_2 max (PG: 1.45±2.44 ml/kg vs CG: 4.14±2.12 ml/kg; $P<0.012$). Moreover, data on individual delta performance between the PG and CG revealed the tendency for improvement in the CG compared to the PG across several measures, including right handgrip (6 individuals vs. 5 individuals), leg dynamometer (9 individuals vs. 7 individuals), back dynamometer (10 individuals vs. 9 individuals) (**Figure 2**), and VO_2 max (11 individuals vs. 8 individuals) (**Figure 3A**). The recovery heart rate after the MFT test showed a significant decrease at each time point post-test. However, there were no differences in the recovery heart rate between groups (**Figure 3B**).

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Table 2. Performance test results between and within groups.

Variable	Placebo (n = 11)	Caffeine (n = 11)	P-value[a]
Strength test			
Right handgrip (kg)			
Before	38.58 ± 7.63[c]	39.97 ± 5.37	0.628
After	37.95 ± 7.11	40.42 ± 6.85	0.414
P-value[b]	<0.001	0.006	
Left handgrip (kg)			
Before	34.96 ± 6.78	37.45 ± 6.72	0.397
After	35.42 ± 8.03	37.93 ± 6.42	0.427
P-value	<0.007	<0.001	
Leg dynamometer (kg)			
Before	79.84 ± 37.58	91.93 ± 23.38	0.376
After	111.45 ± 36.76	108.86 ± 19.25	0.839
P-value	0.016	0.146	
Back dynamometer (kg)			
Before	82.79 ± 16.43	92.81 ± 18.74	0.197
After	91.91 ± 19.58	101.45 ± 23.17	0.309
P-value	0.001	<0.001	
Endurance test			
VO_2 max (mL/kg)			
Before	37.79 ± 5.59	37.85 ± 5.45	0.982
After	39.45 ± 5.87	41.98 ± 5.33	0.266
P-value	<0.001	<0.001	

[a]: obtained from the independent t-test; [b]: Obtained from paired t-test; [c]: Mean±SD.

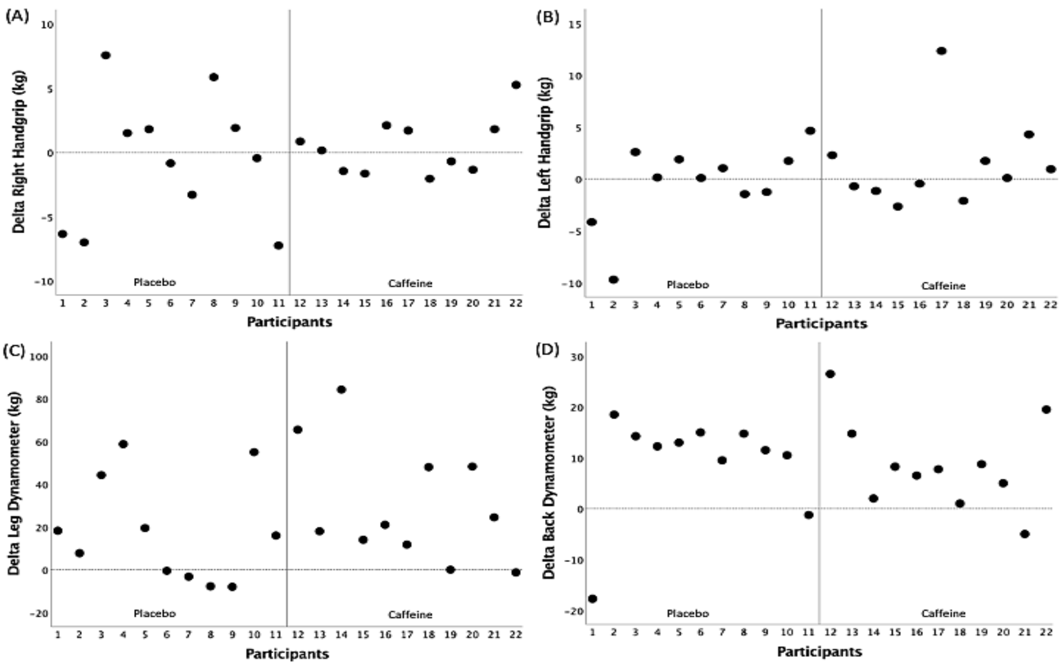

Figure 2. Endurance test results using the multiple fitness test (MFT).

(A) Individual responses to caffeinated chewing gum on VO2 max. P-value was tested using a repeated-measures ANOVA. Within-subject effects: time point, *P*<0.001; time point intervention, *P*<0.012; (B) Post-exercise heart rate variability (HRV). Within-subject effects: minute factor, *P*<0.001. Statistical significance was set at *P*<0.05.

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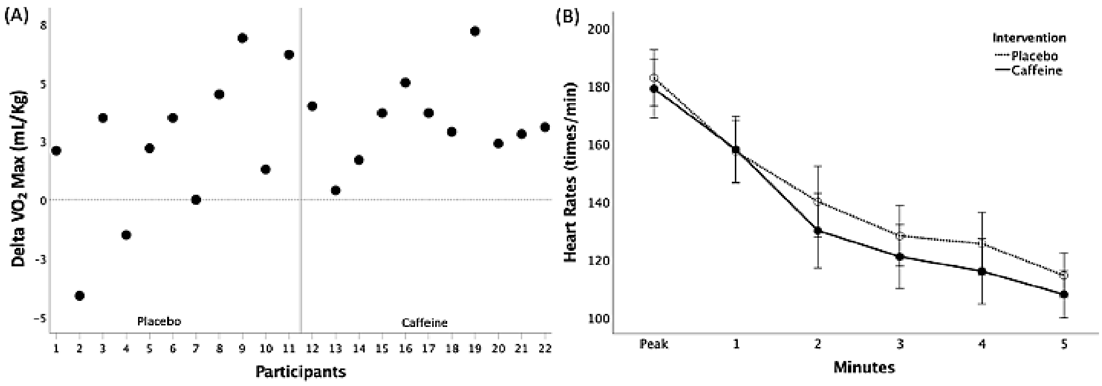

Figure 3. Endurance test results using the multiple fitness test (MFT).

(A) Individual responses to caffeinated chewing gum on VO2 max. P-value was tested using a repeated-measures ANOVA. Within-subject effects: time point, *P*<0.001; time point intervention, *P*<0.012; (B) Recovery heart rate after MFT. Within-subject effects: minute factor, *P*<0.001. Statistical significance was set at *P*<0.05.

Discussion

It was confirmed that the primary hypothesis that a caffeine dose of ~180 mg or ~3 mg/kg body weight in caffeinated chewing gum increased VO_2 max among physically active individuals compared to placebo without affecting the post-exercise heart rate variability (HRV) (**Figure 3A**). However, VO_2 max within groups showed no significant difference. Moreover, caffeinated chewing gum failed to significantly improve strength.

In contrast with a previous study, caffeine consumption did not significantly change VO_2 max after a maximal incremental test (MIT) among nine healthy individuals (Brietzke *et al.*, 2017). The study suggested that an increase in performance outcomes occurred without alterations in VO_2 max, likely due to a reduced rating of perceived exertion (RPE) at maximal effort levels. In agreement with a previous randomized controlled trial, caffeine raised VO_2 max in elite athletes, contributing to an improvement in high-intensity endurance performance (Stadheim *et al.*, 2021). A meta-analysis of 32 studies revealed that a low dose of caffeine (100-300 mg or 2-4 mg/kg) in the form of chewing gum is rapidly absorbed and utilized, positively impacting most exercise and physiological performance (Yang *et al.*, 2024). Similarly, a previous study showed an increased endurance among a study population due to the caffeine intake, with a sample-weighted VO_2 max improvement of 3.83 ml/kg/min from an average baseline of 41.02 ml/kg/min to 44.85 ml/kg/min (Usman *et al.*, 2017). Caffeine enhances VO_2 max primarily by increasing blood flow to the heart and muscles during exercise, which allows for more efficient oxygen uptake and delivery (Brietzke *et al.*, 2017).

This study evaluated the effect of pre-exercise after caffeinated chewing gum consumption. Post-exercise heart rate variability (HRV) was not significantly different between the placebo and caffeine groups. This finding aligns with a meta-analysis reporting that caffeine intake does not affect heart rate recovery after exercise. The safety of caffeine is estimated through cardiac autonomic control (Porto *et al.*, 2022). The study showed increased and peaked HRV after exercise before tremendously reducing within a few minutes in both caffeine and placebo groups. The heart recovery rate between the placebo and caffeine groups was not significantly different. This suggests that caffeine consumption in this trial can maintain the cardiac autonomic control and is safe to use during exercise.

There are possible mechanisms through which caffeine consumption affects performance among individuals. After caffeine is ingested, a higher performance in time trials requires increased power production and is associated with higher heart rate and ventilation. The increased workload after caffeine consumption also elevates cardiac output

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and oxygen uptake. The active components of caffeine have a physiological impact by constraining the ability of the body to increase blood flow during exercise, which may promote efficient oxygen use (Usman *et al.*, 2017). Caffeine improves performance, at least partly, by inhibiting adenosine receptor activity (Aguiar Jr *et al.*, 2020). Adenosine receptors are expressed in tissues including the brain, muscles, heart, lungs, and blood vessels (Fredholm *et al.*, 1999). Therefore, theoretically, caffeine-induced adenosine receptor inhibition can alter various physiological mechanisms contributing to improved endurance performance (Stadheim *et al.*, 2021) .

The International Society for Sports Nutrition (ISSN), the International Olympic Committee (IOC), and the World Anti-Doping Agency (WADA) classify caffeine intake as low (<3 mg/kg), moderate (≥ 3 mg/kg up to 6 mg/kg), and high (9 mg/kg) (Porto *et al.*, 2022). Based on this classification, the caffeine used in this study (~ 3 mg/kg) was categorized as a low prescription dosage. The findings showed that the low dosage had no significant effect on strength among the participants. This dosage was prescribed considering its safety, and none of the adverse effects related to caffeine, such as anxiety, headaches, nausea, and restlessness, were reported during this trial. Overall, the consumption of caffeine can provide benefits in the VO_2 max in active individuals. However, the effects of caffeine on VO_2 max tend to be more inconsistent and are likely dependent on an individual's tolerance levels and withdrawal durations from caffeine.

This study found that caffeinated chewing gum did not affect strength performance as measured by handgrip and dynamometer. In contrast, a meta-analysis discovered that caffeine consumption significantly increases isometric handgrip strength. Caffeine consumption in small doses (1–3 mg/kg) or moderate to high doses (5–7 mg/kg) was observed to have an ergogenic effect (Grgic, 2022). Harty *et al.* found that caffeine timing improved lower-body muscular performance (Harty *et al.*, 2020). These results were contradicted by the findings of this study. According to Norum *et al.*, the fundamental mechanism by which caffeine may promote maximal strength and power is likely related to enhanced motor unit recruitment and voluntary muscle activation of the relevant muscles (Norum *et al.*, 2020).

While the study provides insightful information about aerobic capacity among the physically active population, it is crucial to recognize several limitations when interpreting the results. These limitations encompass concerns regarding the absence of long-term analysis and sample size due to financial constraints. Through pre-experimental standardization for each respondent, this study attempted to account for confounding variables. However, environmental factors could have impacted the results.

Conclusion

This study concluded that caffeine dose of ~180 mg or ~3 mg/kg body weight in chewing gum increased maximal oxygen uptake among physically active individuals while maintaining the cardiac autonomic control. However, the effect of caffeine was dependent on an individual's tolerance level. Furthermore, caffeinated chewing gum did not affect strength among physically active students.

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Authors' contributions

Purnomo M, Rohmah Mayasari N, Yanuar Dini C, and Fathur Rohman M designed the research methods and interpreted the results. Rohmah Mayasari N performed the data analysis. Rohmah Mayasari N, Labib Siena Ar Rasyid M, and Yanuar Dini C drafted the paper and approved the submitted paper. Rohmah Mayasari N performed critical revision of the manuscript for important intellectual content.

Conflict of interest

The authors declared no conflicts of interest.

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