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The Effect of Caffeine on VO2Max in Adolescent Athletes

Erfita Anasha Wiraida [1] *, Sarah Handayani [2]

[1 2] Universitas Muhammadiyah Prof. Dr. HAMKA, Special Capital Region of Jakarta, Indonesia

* Corresponding Author: nckediri02@gmail.com

Abstract: VO2max is the maximum amount of oxygen used per minute by an athlete during exercise. The higher an athlete's VO2max, the higher their fitness and performance. VO2max is influenced by genetics, age, gender, body composition, nutritional intake, and duration of training. Good nutritional intake can increase lung and muscle endurance and delay fatigue in athletes over a long period of time. Caffeine consumption has a stimulating effect on the central nervous system. Many athletes currently consume caffeine as a stimulant to improve performance. The purpose of this study was to determine the effect of caffeine on VO2max in adolescent athletes. The method used in this study was a Systematic Literature Review (SLR). Articles collected through Google Scholar, Plos One, and PubMed Journal related to the effect of caffeine on VO2max values in adolescent athletes published between 2015 and 2025 in English and Indonesian were obtained from 244 related articles. The results obtained from the selected articles showed a significant effect of caffeine administration on adolescent VO2max values. Low or moderate doses of caffeine have an effect. However, the highest VO2max increase value was achieved when caffeine was administered according to body weight.

Keywords: Caffeine, VO2Max, Adolescent, Athletes

Introduction

Heart and lung capacity, commonly known as VO2max (Maximum Oxygen Volume), is the maximum amount of oxygen an athlete uses per minute during exercise. This means that the higher the oxygen intake (in liters per minute or millimeters/minute/kg of body weight), the greater the energy used for activity. Generally, VO2max values range from 30 to 60 ml/kg/minute. A higher VO2max indicates a higher level of fitness and performance for an athlete. However, a lower VO2max indicates suboptimal performance (Debbi and Cerika, 2016).

VO2max measurements can be used as a benchmark for an athlete's performance. An athlete's VO2max should be higher than that of the general population. Athletes with high VO2max values can exercise at high intensities without experiencing fatigue (Sauma et al., 2019). One way to achieve optimal VO2max is through continuous, long-duration training. Exercises that can be performed include aerobics/cardio, exercises that stimulate the heart rate, lungs, and muscles to accelerate.

VO2max can be measured using a Cardiopulmonary Exercise Test (CPET). Several sports that are expected to have a high VO2max are endurance sports such as marathons, swimming, cycling, middle-distance running, and so on. VO2max is influenced by genetics, age, gender, body composition, nutritional intake, and duration of training (Snarr, 2018). This VO2max is one indicator of an athlete's physical fitness. VO2max can also be used to monitor improvements in physical training programs.

Data from the Development Index Survey conducted by the Ministry of Youth and Sports in 2023 showed that the athlete's performance index was 0.172, an increase from the previous year. However, this data still indicates that athletes' achievements based on medal tallies are still less than optimal (scale 0-0.499 low; 0.5-0.7 medium; 0.8-1 high). Furthermore, factors influencing athletes' performance include training, costs, equipment, support, and nutrition (SDI, 2023). Good nutrition can improve lung and muscle endurance and delay fatigue in athletes over the long term.

An athlete needs to understand nutritional intake that can increase endurance for optimal performance. In addition to macro and micronutrients, athletes sometimes consume stimulants during strenuous activities. Caffeine in coffee is often used as a stimulant, providing increased stimulation, thus improving endurance and training frequency. Caffeine can affect muscles by converting fat into energy, thereby increasing calcium levels in muscle cells. Thus, caffeine can prevent muscle fatigue. Caffeine has a stimulating effect on the central nervous system (Hayati, 2012). Caffeine can be found in coffee beans, tea leaves, chocolate, non-alcoholic soft drinks, and so on.

To date, many athletes consume caffeine as a stimulant and ergogenic agent. In fact, caffeine is a frequently used substance due to its ergogenic effects, which influence sports performance (Gabriella et al., 2019). Based on this background, the author is interested in discussing the effect of caffeine on heart and lung capacity (VO2max) in adolescent athletes, based on relevant previous research.

Method

This study was a systematic literature review using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) appraisal tool. The research steps included determining the research topic, conducting a literature search, screening data, determining inclusion criteria, and analyzing and summarizing data. Articles were searched using Google Scholar, Plos One, and PubMed journals, using keywords such as adolescent athletes, caffeine, and VO2max.

The steps taken were: (1) defining the problem; (2) conducting a literature search in Google Scholar, Plos One, and PubMed journals; (3) selecting data based on the year of the study, title, abstract, and research methods; (4) checking for data duplication using Mendeley software; and (5) assessing the quality of data that met the inclusion and exclusion criteria.

The inclusion criteria for this study were articles related to caffeine administration or consumption interventions in adolescent athletes and VO2max values measured using a treadmill or bicycle running test using a mask connected to an oxygen volume meter, a bleep test, a sprint test, a push-up test, a strength test, or using a CPET device. The collected articles were Indonesian and English-language literature published in Sinta-indexed journals within the last 10 years (2015-2025). Exclusion criteria were studies in languages other than Indonesian and English, published before 2015, and articles unrelated to caffeine intake, VO2max, and subjects other than adolescent athletes.

A search for articles using the keywords "caffeine," "VO2max," and "athlete" between 2015 and 2025 yielded 244 journals, which were screened to yield five articles

related to caffeine consumption and VO2max in athletes. The article selection process used the Prisma Flow Diagram as follows:

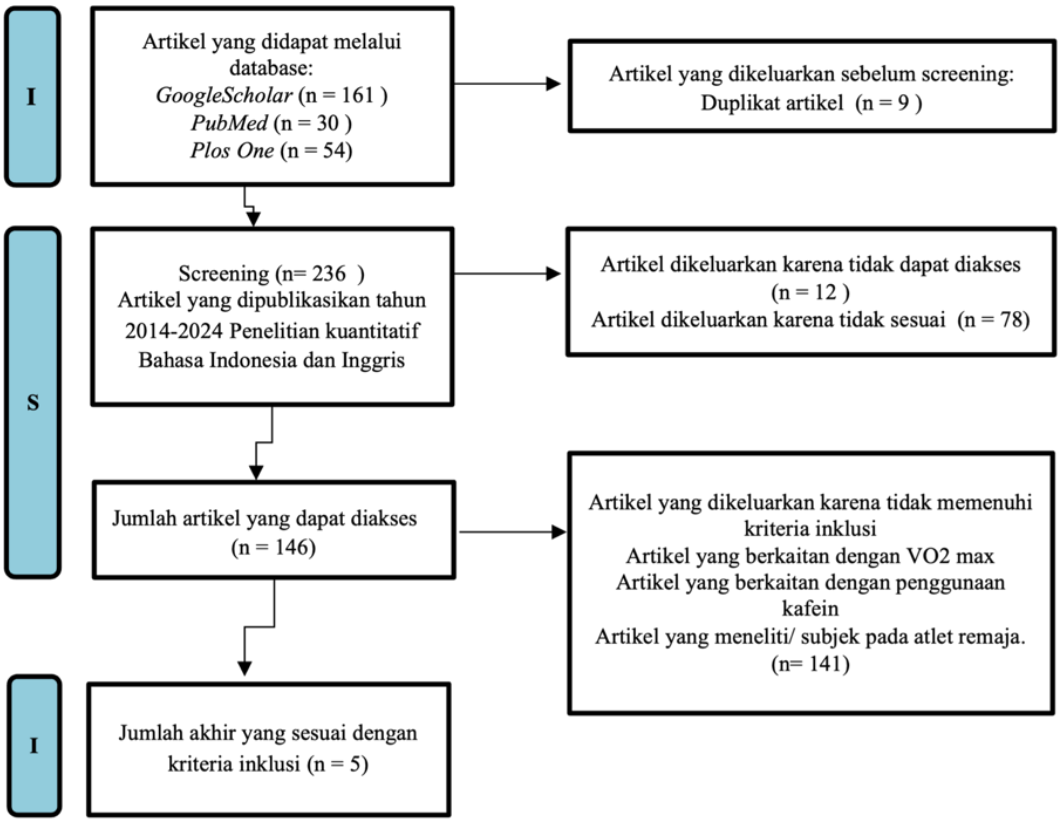

Figure 1. PRISMA Diagram

Results & Discussion

Results

The research article selection process used the PRISMA Diagram (Figure 1). The initial 244 articles were obtained from PubMed Journal, Google Scholar, and Plos One publication. Duplicate articles were then identified and removed (n=9). Next, a screening stage was conducted by selecting titles and abstracts. 90 articles were excluded due to inappropriateness and inaccessibility. A total of 146 accessible articles were then screened again according to the inclusion criteria: articles with experimental designs or interventions such as caffeine administration, and measurements of VO2max levels using various tests, such as the bleep test, CPET, sprint test, treadmill test, push-up test, and MFT strength test. 141 articles did not meet the inclusion criteria and were excluded. Thus, the final selection of articles that met the criteria was 5.

The overall results of the article selection conducted in this SLR are described in detail as follows;

Tabel 1. Selected Articles

No.	Article Title	Author and Year	Research Population	Method	Results
1	The Effect of Caffeine on VO2Max Athletes Ability	Arifuddin Usman, Arimbi, Muriyati (2017)	Badminton athletes with 25 participants. Treatment with pre and post experiments	Kuantitatif Quasi Experimental	The average results of VO2max ability of athletes with caffeine were higher than VO2max of athletes without caffeine, namely 44.85 ml/kg/minute.
2	The Effect of Caffeine on Increasing Vo2max in Karate Athletes	Rithwan Setiawan Malohing, Mochamad Purnomo (2023)	Eight karate athletes aged 16-18 years old participated. All participants were tested pre- and post-intervention	Kuantitatif Quasi Experimental	The intervention involved giving participants double shots of espresso formed into coffee jelly/gummy. Caffeine administration resulted in a 1.02% increase in VO2max. The mean before caffeine administration was 6.788 and after caffeine administration was 6.975. This indicates an increase in VO2max levels in karate athletes before and after caffeine consumption.
3	The Effect of Caffeine Use on Vo2max and Heart Rate After Exercise in Junior Athletes of the Karo Taekwondo Club	Julius Boy Nesra Basgimata Barus, Janwar Frihasan Sinuraya, Tommy Hejeprinta (2022)	Karo Taekwondo Club junior karate athletes numbering 60 people with 30 people in the control group and 30 people in the treatment group	Control Group Design (Quasi Experimental)	The intervention was in the form of caffeine in the form of 15-gram instant coffee containing 1.16% caffeine then dissolved in 100 ml of hot water. Based on the fatigue time, the VO2max results were higher in the treatment group, namely 33.8532 ml / kg / minute, while the average VO2max value of the control group was 30.5612 ml / kg / minute. While VO2max was based on the pulse rate, the control group was lower (135.501 x / minute) than the treatment group (140.145 times / minute), so there was no significant difference after measuring the pulse rate between the control and treatment groups.
4	The Effect of Caffeine on Maximum Oxygen Consumption during Rest, Exercise, and Return to Original State	Saeedeh Yazdani Saeed Yazdani (2018)	Twenty-four volleyball athletes aged 14-17 years old. The treatment consisted of a pre- and post-experiment. The intervention was administered 60 minutes before the test	One Group Pretest-Posttest Design (Quasi Experimental)	The results showed a significant difference (0.460) between subjects receiving placebo and those receiving caffeine at 5 mg/kg body weight. The difference was 3.431 ± 0.326 for athletes receiving placebo, and 3.981 ± 0.560 for athletes receiving caffeine.
5	Cardiovascular Endurance Response of Athletes to the Effects of Caffeine Intake	Arimbi (2024)	A total of 25 athletes were treated with pre and post experiment treatment with a 3-day rest period	Pra Experimental	Intervention by administering 5 mg of caffeine per kg of body weight showed a difference in the average VO2max in athletes after administering 5 mg/kg of caffeine, namely 44.85 ml/kg/min compared to VO2max before administering caffeine, namely 41.02 ml/kg/min. With an average VO2max capacity in athletes of 3.83 ml/kg/min.

Based on the results of the intervention analysis in the articles, five articles collected showed a significant association with increased VO2max after the intervention, namely caffeine administration. The increase in VO2max in three studies showed VO2max values of 33.852 ml/kg/minute and 44.85 ml/kg/minute, respectively. Another study also showed an increase of 1.02%. In the systematic literature review analysis, the authors used a descriptive method.

Articles were assessed based on the "PICO" criteria: "Population," "Intervention," "Comparison," and "Outcome," which are presented as follows;

Table 2. PICO (Population, Intervention, Comparison, & Outcome)

PICO	Information
Population	Research subjects in adolescent athletes
Intervention	Subject intervention with caffeine consumption
Comparison	Comparison of VO2max on caffeine administration
Outcome	VO2Max value

Based on the article assessment, it was also carried out using the inclusion and exclusion criteria which are described as follows;

Table 3. Inclusion and Exclusion Criteria

No.	Inclusion	Exclusion
1	Research subjects in adolescent athletes	The research subjects were adult athletes or adolescents who were not athletes
2	Subject intervention with caffeine consumption	Subject intervention with caffeine consumption in combination with other ergogenic substances
3	Articles are in Indonesian and English	Articles other than Indonesian and English
4	Articles published between 2015 and 2025	Articles published < 2015

Discussion

One indicator of good athlete performance is achievement. Good athlete performance is demonstrated by several factors, including external factors such as coaching support, organization, coaches, and adequate equipment and facilities. Internal factors include physical health, technique, and mental health (Yulianto and Kusnanik, 2019). Furthermore, this physical health factor is defined as aerobic capacity, indicated by an athlete's fitness level. Good physical fitness affects an athlete's blood circulation and cardiorespiratory function, as well as endurance, speed, and agility during competition (Bryantara, 2019). This impacts an athlete's endurance and performance.

An athlete's physical fitness can be assessed by their VO2max capacity. VO2max is the maximum amount of oxygen an athlete uses per minute during exercise. VO2max is fundamentally influenced by lung and heart function, aerobic muscle metabolism, gender, body composition, exercise duration, and genetics (Giri, 2013). VO2max can be used as an indicator for assessing cardiovascular capacity, respiratory capacity, and metabolic capacity, which is the ability to convert energy.

Caffeine is a type of alkaloid compound found in coffee beans, tea leaves, and cocoa. It forms crystals and is readily soluble in water (Wijayanti et al., 2019). Many sources of caffeine are now being added to foods and beverages, such as beef jerky, peanut butter, and candy. Caffeine in the form of chewing gum further increases blood absorption (Guest et al., 2021). Caffeine is a stimulant of the central nervous system,

cardiovascular system, and respiratory system, which can reduce pain. Furthermore, caffeine has an ergogenic effect on the body, enabling athletes to train and compete for extended periods without significant fatigue (Grgic and Mikulic, 2017). Furthermore, it was reported that there was a 3% increase in performance with barbell back squats and lower body strength training.

Caffeine has an ergogenic effect on individuals who engage in prolonged exercise, and its role in regulating enzymes and activating muscle contractions and skeletal muscle increases calcium ion transport (Hayati, 2012). Further research (Purnomo and Rithwan, 2023) explains that caffeine is the main ingredient in coffee. Caffeine, along with fat as energy, can affect muscles and increase calcium levels in muscle cells. This process reduces fatigue and increases endurance. Caffeine's primary role in the body is to enhance psychomotor activity, thus maintaining alertness and providing physiological effects in the form of increased energy.

According to the WHO, adolescents are defined as children aged 10-19 years. Five selected research articles focusing on adolescents found that caffeine significantly impacts the VO2max of adolescent athletes. The caffeine doses administered to the treatment groups varied, including 15mg, 126mg (double shot espresso), and 5mg/kg body weight. The caffeine was administered in liquid form (drinks) or gummy form (candy). The effects and performance of caffeine on metabolism and its impact on VO2max depend on the dose administered. These results align significantly with research (Arimbi, 2024) that found the average VO2max of athletes after administering 5mg/kg of caffeine was 44.85 ml/kg/minute. This is also in line with research (Saeedah and Saeed, 2018) that athletes who consumed caffeine had an average VO2max value that increased from 3.431 ± 0.326 to 3.981 ± 0.560.

Furthermore, it was explained that athletes who received higher caffeine doses maintained their blood concentrations for longer (Muriyati et al., 2017). Dosing caffeine based on body weight had a greater impact on VO2max (Purnomo and Rithwan, 2023). Dosing appropriately for body weight provides optimal cardiovascular performance. The timing of caffeine intake also has a significant impact. The best time to consume caffeine is two hours before training or competing. This stimulates catecholamine hormones and effectively increases heart rate, as research suggests (Barus, Julius et al., 2022). Optimal caffeine absorption in the body takes approximately 45-60 minutes.

In five research articles, the intervention involved administering caffeine in the form of a drink or gummy before measuring oxygen capacity. Another finding from Arimbi (2024) was that administering caffeine in the form of a coffee drink before training, with a dose based on body weight, increased athlete endurance by more than 20%. In coffee brewed with hot water, caffeine dissolves readily in water in the form of potassium caffeine chlorogenic acid and chlorogenic acid bonds, which are readily absorbed by the body. This contrasts with the study by Purnomo and Rithwan (2023) which used caffeine in the form of gummy candy. Although the intervention still resulted in an increase in oxygen capacity, the results were not very significant, with an r value of 3.416 and a significance value (p) of 0.011 ($p < 0.05$). The absorption of caffeine into the body takes between 45-60 minutes. The metabolic effects of caffeine are greater than those of aminophylline and methylxanthines. Furthermore, caffeine has a significant effect on the central nervous system (CNS) as an adenosine receptor (Husainah and Zulianto, 2024). Cardiovascular endurance, as measured by VO2max, is influenced not only by caffeine consumption but also by rest duration, physical endurance, and the athlete's physical fitness. In sports of short duration and long intervals, or in sports involving a series of matches, pre-match caffeine administration significantly increases heart rate. Combative performance requires a stable, physically and mentally strong state. This means that the type of sport can also influence the effectiveness of caffeine on performance. This aligns

with research by Arimi (2024) that found caffeine can increase endurance in sports of both short and long duration.

Conclusion

This Systematic Literature Review (SLR) explains the significant effect of caffeine consumption on VO2max in adolescent athletes. The increase in VO2max values varied depending on the amount of caffeine administered, ranging from 15 mg, 126 mg (a double shot espresso), and 5 mg/kg body weight. Consuming 15 mg of caffeine before exercise has been shown to increase VO2max in adolescent athletes. Although research results vary widely, caffeine can significantly increase oxygen volume in the heart and lungs.

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