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Factors that affect the maximal oxygen uptake

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ABSTRACT

Background: Physical fitness refers to the body's ability to perform work or physical activities without experiencing excessive fatigue. One of the most important indicators of physical fitness is the maximal oxygen uptake (VO_2max), as a higher score reflects better endurance and lower fatigue during physical activity. Therefore, understanding the factors that influence VO_2max is essential for improving overall physical performance. This study aimed to identify the factors that affect maximal oxygen uptake.

Methods: This study employed a literature review approach using secondary data obtained from research journals related to physical fitness and VO_2max. The journals were sourced from databases such as Google Scholar and PubMed. The authors included journals published within the last ten years.

Results: There were several factors that influenced a person's VO_2max. Males generally have higher VO_2max levels than females. Individuals living in high-altitude areas tend to have higher VO_2max values compared to those living in low-altitude regions. Nutritional status and body mass index (BMI) show a negative correlation with VO_2max, whereas physical activity demonstrates a positive correlation.

Conclusion: The factors that influence the VO_2max include gender, nutritional status, BMI, physical activity, body fat percentage, and living environment.

Keywords: VO_2max, cardiovascular endurance, physical fitness

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Introduction

Physical fitness is the body's ability to perform work or physical activities without excessive fatigue.[1] It is essential for individuals of all ages to support daily activities. According to the 2022 National Report on the Sport Development Index (SDI) by the Ministry of Youth and Sports (Kemenpora), the physical fitness level of Indonesians remains low: 76% are classified as unfit, 53.63% as very unfit and only 5.86% as having a good level of physical fitness.[2]

Regular physical activity is essential for maintaining musculoskeletal, cardiovascular and psychological health.[3] Physical fitness comprises several components, including coordination, endurance, cardiovascular and muscular strength, flexibility, balance, agility, speed, power, and overall strength.[4] It is closely related to physical activity, defined as any movement of the skeletal muscles that requires energy expenditure.[5] The level of physical activity an individual can perform reflects their fitness level, with greater capacity indicating higher fitness. A key indicator of physical fitness is maximal oxygen uptake (VO_2max).[1,6]

VO_2max is the maximum amount of oxygen the body can utilize during physical activity without significant fatigue, typically measured in liters per minute or milliliters per kilogram per minute.[6,7] It serves as a key indicator of cardiorespiratory fitness, as higher VO_2max levels correspond to greater endurance and reduced fatigue. Conversely, low fitness levels decrease VO_2max, impairing an individual's ability to perform daily activities.[1]

Based on a review of several studies, various factors influencing VO_2max have been identified. This study aimed to further investigate these factors and provide insights that may benefit readers by enhancing their understanding of the determinants of VO_2max.

Methods

This study employed a literature review using secondary data from research journals. Journals were identified using keywords such as "VO_2max", "cardiovascular" and "physical fitness" and were sourced from databases including Google Scholar and PubMed. Only journals published within the past

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ten years were considered. From 18 collected journals, five were selected based on their relevance to the research topic.

Results

The literature review reveals consistent factors influencing VO_2max (Table 1). Regarding physical activity, Shete et al. reported that female athletes had a significantly higher mean VO_2max (39.62 ± 2.80 ml/kg/min) than non-athletes (23.54 ± 3.26 ml/kg/min, $p < 0.0001$).[8] This finding is supported by Adelia et al. who observed a significant positive correlation between physical activity and VO_2max ($r = 0.264$, $p < 0.01$).[9]

Body composition also showed a strong relationship with VO_2max. Setty et al. found a significant negative correlation between obesity and VO_2max ($r = -0.88$, $p < 0.05$) and a positive correlation with treadmill heart rate ($r = 0.80$, $p < 0.05$).[10] Similarly, Adelia et al. reported a significant negative correlation between nutritional status (BMI) and VO_2max ($r = -0.496$, $p < 0.01$).[8] Although Shete et al. observed only a weak negative correlation between body fat percentage and VO_2max in athletes ($r = -0.1191$), athletes still had lower mean body fat (24.11 ± 1.83%) compared to non-athletes (29.31 ± 3.86%).[8]

Gender was another determinant, with Nabi et al. reporting that men had a significantly higher mean VO_2max (45.66 ± 8.96 ml/kg/min) than women (37.85 ± 4.3 ml/kg/min, $p < 0.0001$).[11] Environmental factors also influenced VO_2max; Deswandi et al. found that athletes training at high altitudes had higher mean VO_2max (40.2 ml/kg/min) compared to those in lowland areas (37.0 ml/kg/min).[12]

Discussion

VO_2max is the maximum amount of oxygen the body can utilize to perform daily activities without significant fatigue.6 It serves as an indicator of physical fitness, reflecting the cardiorespiratory system's efficiency in delivering oxygen throughout the body.13,14 Aerobic capacity represents the energy available for physical activity, while anaerobic capacity provides additional energy when aerobic sources are depleted, producing lactate and eventually causing fatigue.[1,14] Enhancing VO_2max is therefore essential to increase the frequency and intensity of physical activities an individual can perform. Based on the reviewed literature, multiple factors have been identified that influence VO_2max.

Physical activity has a significant impact on VO_2max. Shete et al. compared female athletes and non-athletes and found that athletes exhibited higher average VO_2max levels indicating a positive correlation between physical activity and VO_2max. The study also showed that body fat percentage influences VO_2max with athletes having lower average body fat than non-athletes. Correlation analysis revealed a negative relationship, suggesting that lower body fat contributes to higher VO_2max in athletes.[8]

However, the correlation between VO_2max and body fat percentage was not highly significant, suggesting that although individuals with better physical fitness generally exhibit higher VO_2max levels, body fat percentage may not be a strong determinant.[8,9,15] In contrast, Huldani et al. reported a significant negative correlation between body fat percentage and VO_2max, indicating that higher body fat is associated with lower aerobic capacity. Increased adipose tissue may contribute to fat accumulation in blood vessels, hindering blood flow and reducing oxygen transport efficiency.[15]

Gender is an important factor influencing VO_2max. Women generally have smaller hearts, lungs, and lower hemoglobin mass than men, which limits oxygen delivery to working muscles.[16] This is supported by Nabi et al. who found that men had significantly higher average VO_2max values than women. Body mass index (BMI) also affects VO_2max. BMI, an anthropometric index calculated by dividing body weight (kg) by height squared (m^2) is used to classify nutritional status with values above 30 categorized as obesity according to the WHO.17 Setty et al. reported a negative correlation between obesity and VO_2max, indicating that higher BMI is associated with lower aerobic capacity.[10] Similarly, Nabi et al. found that non-obese men and women had higher VO_2max levels than their obese counterparts. This relationship is closely linked to nutritional status and body fat percentage; individuals with higher BMI often exhibit increased body fat, which may narrow blood vessels and impair oxygen distribution to the heart and lungs.[11,18] Consistent with these findings, Adelia et al. also reported a significant negative correlation between nutritional status and VO_2max, suggesting that higher nutritional status is associated with lower aerobic capacity.[9]

Deswandi et al. found that environmental conditions significantly influence VO_2max. Athletes training in lowland areas exhibited lower VO_2max levels than those training in high-altitude regions. This difference may be attributed to environmental variations and differing levels of physical activity among athletes. At higher altitudes, reduced oxygen availability triggers physiological adaptations such as increased lung ventilation and enhanced tissue vascularization, which collectively improve oxygen utilization efficiency.[12,19]

We have to acknowledge that this study had several limitations. Although this study summarizes important physiological and environmental factors, its focus on healthy, athletic groups limits its applicability to clinical or sedentary cohorts. A certain amount of methodological variability is introduced by including research from different testing methods and altitudes, which could affect the consistency of the reported maximal values.[20].

Conclusions

Based on the five reviewed journals, the factors influencing maximal oxygen uptake (VO_2max) include gender, nutritional status, BMI, physical activity level, body fat percentage and living environment.

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Table 1. Results summary of the factors that affect the maximal oxygen uptake (VO2max).

Authors	Title	Methods	Result
Shete et al., (2014)[8]	A study of VO_2max and body fat percentage in female athletes	Study Design: Cross-sectional study. Participants: 50 females aged 17–22 years. Measurements: VO_2max was assessed using the Queen's College Step Test and body fat percentage was determined using skinfold calipers. Inclusion Criteria: The athlete group comprised healthy females aged 17–22 years who had engaged in regular physical training for over two years, while the control group included healthy female college students of the same age who did not participate in regular exercise or sports activities. Exclusion Criteria: Participants with systemic or chronic diseases or musculoskeletal injuries that could affect the step test were excluded.	Study results show that athletes had a significantly higher mean VO_2max (39.62 ± 2.80 ml/kg/min) than non-athletes (23.54 ± 3.26 ml/kg/min, $p < 0.0001$) and a lower mean body fat percentage (24.11 ± 1.83% vs. 29.31 ± 3.86%, $p < 0.05$). Pearson correlation analysis indicated a negative association between VO_2max and body fat in both groups (athletes: $r = –0.119$; non-athletes: $r = –0.134$), suggesting that higher body fat is linked to lower aerobic capacity although this correlation was not statistically significant.
Nabi et al., (2015)[11]	Assessment of cardiovascular fitness [VO_2max] among medical students by Queen's College Step Test	Study Design: Cross-sectional study. Participants: 57 healthy medical students aged 18–24 years. Measurements: VO_2max was indirectly estimated using the Queen's College Step Test (QCST) and calculated from post-exercise heart rate recovery. Inclusion Criteria: Healthy men and women aged 18–25 years who were non-smokers and did not consume alcohol. Exclusion Criteria: Individuals taking medications, regularly engaging in structured physical activity or with a history of acute or chronic illness.	Study results show that mean VO_2max was significantly higher in men (45.66 ± 8.96 ml/kg/min) than in women (37.85 ± 4.3 ml/kg/min, $p < 0.0001$), indicating greater aerobic capacity in men. Non-obese men (46.1 ± 8.8 ml/kg/min) and women (38.16 ± 3.9 ml/kg/min) had higher mean VO_2max than their obese counterparts (men: 44.7 ± 9.6 ml/kg/min, $p = 0.068$; women: 37.12 ± 5.6 ml/kg/min, $p = 0.5853$). Although VO_2max tended to decrease with higher BMI, these differences were not statistically significant.

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Setty et al., (2013)[10]	Correlation Between Obesity and Cardio Respiratory Fitness	Study Design: Cross-sectional study. Participants: 60 males aged 18–22 years. Measurements: VO2max measurement was conducted using the Treadmill Jogging Test (TMJ). Inclusion Criteria: Healthy males aged 18–22 years from Kolar city, willing to complete a physical activity questionnaire and provide written informed consent. Exclusion Criteria: Individuals with health conditions affecting test results, unwilling to complete the questionnaire, or who engaged in strenuous activity within 2–3 hours before testing.	Obesity is negatively correlated with VO_2max ($r = -0.88$, $p < 0.05$), indicating that higher BMI is associated with lower VO_2max. Obesity is positively correlated with treadmill heart rate ($r = 0.80$, $p < 0.05$), indicating that higher BMI is associated with higher heart rate during the treadmill test.
Deswandi et al., (2019)[12]	Comparison of Environmental Adaptation for Athletes Training in High-altitude and Low-altitude Areas on VO2max and Hemoglobin Levels in Anaerobic Sports	Study Design: Comparative study. Participants: Athletes engaged in anaerobic sports. Measurements: VO_2max assessed using the Bleep Test Inclusion and exclusion criteria: Not clearly specified	Athletes in lowland areas had a mean VO_2max of 37.0 (median = 35.7, SD = 5.1), while those in highland areas had a mean of 40.2 (median = 39.5, SD = 3.0). These results suggest that individuals living at high altitudes tend to have higher VO_2max than those at low altitudes.
Adelia et al., (2022)[9]	The Relationship Between Nutritional Status and Physical Activity with VO2max in Employees of Aisyah University Pringsewu in 2021	Study Design: Cross-sectional study. Participants: 78 adults aged 22-60 years. Measurements: VO_2max was assessed using the 20-Meter Shuttle Run Test, nutritional status was determined by Body Mass Index (BMI) and physical activity was evaluated using a 2×24-hour recall (weekday and weekend) with the International Physical Activity Questionnaire (IPAQ) and the Physical Activity Ratio (PAR) table. Inclusion and exclusion criteria: Not explicitly stated	Nutritional status was significantly negatively correlated with VO_2max ($r = -0.496$, $p < 0.01$), indicating that higher nutritional status is associated with lower VO_2max. Conversely, physical activity was significantly positively correlated with VO_2max ($r = 0.264$, $p < 0.01$), indicating that higher physical activity levels are associated with higher VO_2max.

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Ethical clearance

This review used only publicly available published articles, therefore informed consent and formal ethical approval were not required.

Conflict of interest

The authors declare that they have no financial or other conflicts of interest that would have affected the study, writing or publication of the work. Author attests that the study and paper were carried out with complete scientific integrity, free from any outside or personal influences that would compromise the validity or objectivity of the results.

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Author contributions

IGAWI designed the study, collected the data and drafted the initial manuscript, while IP and MW assisted with data collection and contributed revisions to the manuscript.

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