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Association Between Lower Limb Strength and VO_2max in Recreational Runners

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Abstract

Background: Participation in recreational running has increased in Indonesia, but evidence on the relationship between lower limb muscle strength and cardiovascular endurance remains limited.
Objective: To determine the association between lower limb muscle strength and cardiovascular endurance among recreational runners in Denpasar, Bali.
Methods: A cross-sectional study was conducted among 57 recreational runners from the Urban Stride Bali community. Lower limb muscle strength was measured using a leg dynamometer, while cardiovascular endurance was assessed using the Cooper 12-Minute Run Test and estimated VO_2max. Data were analysed using Spearman's rank correlation.
Results: Mean lower limb muscle strength was 66.82 ± 28.58 kg, while mean VO_2max was 47.52 ± 14.27 ml/kg/min. A very strong positive association was found between lower limb muscle strength and cardiovascular endurance (r_s = 0.833; 95% CI: 0.726–0.902; p = 0.001).
Conclusion: Lower limb muscle strength was strongly associated with cardiovascular endurance in recreational runners. However, the cross-sectional design and lack of assessment of potential confounders, including body composition and training history, limit causal interpretation.

Keywords
aerobic capacity; muscle strength; physical endurance; recreational athletes; running; VO_2max

Introduction

Recreational running has become one of the fastest-growing forms of physical activity worldwide because of its accessibility, affordability, and well-documented health benefits. In Indonesia, participation in recreational running events such as the Bali Marathon, Pocari Sweat Run, and other community-based races has increased substantially over the past decade, reflecting greater public awareness regarding physical fitness and healthy lifestyles.[1] The rapid expansion of recreational running communities in Bali has also contributed to increased participation among young adults who engage in running primarily for health promotion, recreation, and social interaction rather than elite athletic competition. Despite this growing participation, recreational runners frequently demonstrate heterogeneous physical fitness profiles due to variations in training intensity, exercise history, and physical conditioning strategies.[2]

Cardiovascular endurance is considered one of the most important determinants of running performance and overall aerobic fitness. Maximal oxygen uptake (VO_2max) reflects the integrated ability of the cardiovascular, respiratory, and muscular systems to transport and utilise oxygen during sustained physical activity.[3] Higher VO_2max values are associated with improved endurance performance, reduced fatigue during prolonged exercise, and better cardiometabolic health outcomes.[4] However, VO_2max in recreational runners may vary substantially according to age, sex, training status, body composition, and musculoskeletal capacity.[5] These variations are particularly relevant in recreational populations because training programmes are often unstructured and are commonly performed without professional supervision.

Among the musculoskeletal factors associated with endurance performance, lower limb muscle strength has attracted increasing scientific attention. The quadriceps, hamstrings, gluteal muscles, gastrocnemius, and soleus play essential roles in force generation, shock absorption, propulsion, and postural stability during running.[6] Adequate lower limb strength may improve mechanical efficiency during repetitive running cycles, thereby reducing excessive energy expenditure and delaying muscular fatigue.[7] Previous physiological studies have also demonstrated that resistance-oriented adaptations may improve neuromuscular recruitment efficiency, muscular oxidative capacity, and movement economy, which collectively support endurance performance.[8] Nevertheless, although several studies have demonstrated beneficial associations between muscular strength and endurance-related outcomes, the underlying mechanisms remain multifactorial and incompletely understood, particularly in recreational runners.[9]

The relationship between lower limb muscle strength and cardiovascular endurance may also be influenced by several confounding factors. Body composition, especially lean muscle mass and adiposity, is strongly associated with both muscular performance and VO_2max values.[10] Individuals with higher lean body mass generally demonstrate greater force production capacity, whereas excess body fat may reduce aerobic efficiency because of increased metabolic demand during locomotion. In addition, training history, resistance exercise exposure, nutritional intake, hydration status, and exercise recovery may influence both muscle strength and aerobic performance outcomes.[11] These factors are important considerations because recreational runners commonly exhibit considerable variability in training characteristics and lifestyle behaviours.

Sex-related physiological differences should also be considered when examining muscular strength and aerobic endurance. Males generally demonstrate higher absolute muscle mass, haemoglobin concentration, and maximal oxygen transport capacity than females, contributing to higher average VO_2max and strength values.[12] Conversely, females may exhibit different fatigue resistance and substrate utilisation characteristics during endurance exercise.[13] Therefore, interpretation of the association between lower limb strength and cardiovascular endurance requires careful consideration of sex-specific physiological differences, particularly in mixed-sex recreational populations.

Previous studies investigating the relationship between muscular strength and endurance performance have predominantly involved elite or competitive athletes undergoing structured training programmes.[8,9] Consequently, the findings may not be directly generalisable to recreational runners, who often present with more variable fitness characteristics and inconsistent resistance-training exposure. Evidence from Southeast Asian populations, particularly recreational runners in Indonesia, also remains limited. Furthermore, many previous investigations focused primarily on running economy or athletic performance outcomes rather than directly evaluating the association between lower limb muscle strength and estimated VO_2max in community-based recreational runners. This limitation highlights an important research gap because recreational athletes represent a rapidly expanding physically active population with distinct physiological and behavioural characteristics.

Although direct cardiopulmonary exercise testing (CPET) remains the gold standard for VO_2max measurement, its implementation requires sophisticated laboratory equipment, specialised personnel, and substantial financial resources.[14] Consequently, field-based assessments such as the Cooper 12-Minute Run Test remain widely used in exercise physiology and sports science research because they are practical, cost-efficient, and demonstrate acceptable validity for estimating aerobic capacity in physically active populations.[15] Several studies have reported strong correlations between Cooper Test performance and laboratory-measured VO_2max, supporting its applicability in large-scale field studies and recreational athletic settings.[15,16] However, estimated VO_2max derived from field testing still possesses lower precision than direct gas-analysis methods, and this limitation should be acknowledged when interpreting results.

From a physiotherapy and sports science perspective, understanding the association between lower limb muscle strength and cardiovascular endurance may contribute to the development of more comprehensive exercise programmes for recreational runners. Identification of this relationship may support evidence-based exercise prescription strategies integrating aerobic and resistance-training components to improve physical fitness and potentially reduce running-related injury risk.[7,17] However, because most currently available evidence originates from non-Indonesian athletic populations, further investigation within local recreational running communities remains necessary.

Therefore, this study aimed to determine the association between lower limb muscle strength and cardiovascular endurance among recreational runners in Denpasar, Bali. It was hypothesised that greater lower limb muscle strength would be significantly associated with higher cardiovascular endurance, as reflected by estimated VO_2max values, in recreational runners.

Methods

This study employed an analytical observational design with a cross-sectional approach to evaluate the association between lower limb muscle strength and cardiovascular endurance among recreational runners in Denpasar, Bali. The study was conducted between March and May 2026 at Lapangan Renon, Denpasar, Bali, Indonesia. Data collection sessions were scheduled between 06:30 and 09:00 Central Indonesian Time (WITA) to minimise the influence of excessive environmental heat on physiological performance. Ambient temperature and relative humidity were monitored during each session using a portable environmental monitor. Measurements were postponed when rainfall occurred or ambient temperature exceeded 25°C to reduce the potential influence of environmental stress on cardiovascular performance.

The target population consisted of recreational runners affiliated with the Urban Stride Bali running community. Participants were recruited using purposive sampling after coordination with community administrators and dissemination of recruitment information through the community's official social media platform. Purposive sampling was selected to ensure that recruited participants fulfilled predefined running-related characteristics relevant to the study objective; however, this technique may increase the risk of selection bias and limit broader population generalisability.

Eligibility criteria were established before recruitment. Inclusion criteria included: (1) male or female recreational runner aged 17–39 years; (2) participation in regular running exercise at least twice weekly for a minimum of three consecutive months; and (3) willingness to participate through written informed consent. Exclusion criteria included: (1) inability to complete the Cooper 12-Minute Run Test; (2) current lower extremity musculoskeletal injury; (3) history of cardiovascular or respiratory disease limiting vigorous physical activity; and (4) withdrawal during data collection.

Sample size determination was based on the Lemeshow formula for cross-sectional studies using $\alpha = 0.05$, $Z = 1.96$, $p = 0.5$, and margin of error (d) = 13%, resulting in a minimum required sample of 57 participants. The relatively wider margin of error was selected because of the limited accessible recreational running population during the recruitment period. Although correlation-specific power analysis may provide a more statistically robust estimation for association studies, the Lemeshow formula was used to maintain feasibility within the available study population. A total of 57 eligible participants completed all measurements and were included in the final analysis.

Lower limb muscle strength was evaluated using a calibrated leg dynamometer. Prior to data collection, the instrument underwent routine calibration according to manufacturer recommendations to ensure measurement consistency. Leg dynamometry was selected because of its practicality and previously reported acceptable validity and reliability for lower extremity strength assessment.[13] Participants stood on the dynamometer footplate with the knees slightly flexed and trunk maintained in an upright position. Following one familiarisation trial, participants performed two maximal isometric pulling efforts lasting approximately 3–5 seconds each. A standardised verbal encouragement protocol was applied during testing. The highest value obtained from the two attempts was recorded in kilograms (kg). A rest interval of approximately one minute was provided between attempts to minimise fatigue effects.

Cardiovascular endurance was assessed using the Cooper 12-Minute Run Test, a widely used field-based assessment for estimating maximal aerobic capacity.[14] Participants were instructed to cover the greatest possible distance within 12 minutes on a flat standardised running track. Total running distance was recorded in metres and converted into estimated maximal oxygen uptake (VO_2max) using the standard Cooper formula. The Cooper Test was selected because of its practicality, low cost, and acceptable correlation with directly measured VO_2max in physically active populations.[14,15] Nevertheless, estimated VO_2max derived from field testing possesses lower validity than direct cardiopulmonary exercise testing (CPET), and this limitation was considered during interpretation of findings.

To improve procedural consistency, all participants completed measurements during a single testing session. Before testing, participants underwent a standardised 10–15-minute warm-up consisting of light jogging and dynamic stretching. Participants were instructed to avoid vigorous exercise within 24 hours before testing and to maintain normal hydration and nutritional intake. However, dietary intake, caffeine consumption, sleep quality, and hydration status were not objectively controlled. A minimum 10-minute seated recovery period was provided between the leg dynamometer assessment and Cooper Test to minimise residual fatigue. Participants used their habitual running footwear during testing because standardised footwear was not available. Running surface and environmental conditions were standardised across sessions as much as possible. Participants were also asked whether they had previous familiarity with the Cooper Test to reduce learning-related variability.

Several potential confounding variables, including body composition, resistance training history, and training age, were not objectively measured in this study because of limited resources and field-based data collection constraints. Training intensity was collected through self-reported questionnaire categories (light, moderate, vigorous), which may introduce subjective reporting bias. In addition, evaluator blinding was not implemented because all assessments were conducted directly during the same field session.

Data were analysed using IBM SPSS Statistics version 26.0. Descriptive statistics were presented as mean ± standard deviation (SD), median, interquartile range (IQR), minimum–maximum values, frequencies, and percentages where appropriate. Normality testing was performed using the Shapiro–Wilk test. Because lower limb muscle strength data demonstrated non-normal distribution ($p < 0.05$), non-parametric analysis was selected. The association between lower limb muscle strength and cardiovascular endurance was analysed using Spearman's rank correlation coefficient (r_s). Correlation strength was interpreted as weak (0.00–0.39), moderate (0.40–0.59), strong (0.60–0.79), or very strong (0.80–1.00). Confidence intervals (95% CI) were additionally calculated to improve statistical interpretation. Statistical significance was established at $p < 0.05$.

Potential outliers were screened descriptively through minimum–maximum distribution analysis and visual inspection of data dispersion. No missing or incomplete data were identified because all participants completed the full measurement protocol. Multivariable regression analysis was not conducted because the primary objective of this study was limited to evaluating bivariate association patterns within the available sample size.

This study received ethical approval from the Health Research Ethics Commission, Faculty of Medicine, Universitas Udayana/Prof. Dr. I.G.N.G. Ngoerah Hospital, Denpasar, Indonesia (ethical clearance number available on institutional record). All participants provided written informed consent prior to participation. Confidentiality and anonymity of participant information were maintained throughout the research process in accordance with the Declaration of Helsinki.

Results

This analytical observational study employed a cross-sectional design to evaluate the association between lower limb muscle strength and cardiovascular endurance among recreational runners in Denpasar, Bali, Indonesia. The study was conducted between March and May 2026 at Lapangan Renon, Denpasar. Data collection sessions were performed between 06:30 and 09:00 Central Indonesian Time (WITA) to minimise the influence of excessive environmental heat on physiological performance. Ambient temperature and relative humidity were monitored using a portable environmental monitor during each testing session. Measurements were postponed in cases of rainfall or ambient temperatures exceeding 25°C to reduce potential environmental influences on cardiovascular performance.

The target population consisted of recreational runners affiliated with the Urban Stride Bali running community. Participants were recruited using purposive sampling through coordination with community administrators and dissemination of recruitment information via the community's official social media platform. Purposive sampling was selected to ensure that participants fulfilled predefined running-related characteristics relevant to the study objective; however, this technique may increase the risk of selection bias and limit population generalisability.

Eligibility criteria were established before recruitment. Inclusion criteria included: (1) male or female recreational runners aged 17–39 years; (2) participation in regular running exercise at least twice weekly for a minimum of three consecutive months; and (3) willingness to participate by providing written informed consent. Exclusion criteria included: (1) inability to complete the Cooper 12-Minute Run Test; (2) current lower extremity musculoskeletal injury; (3) history of cardiovascular or respiratory disease limiting vigorous physical activity; and (4) withdrawal during data collection.

Sample size was determined using the Lemeshow formula for cross-sectional studies with $\alpha = 0.05$, $Z = 1.96$, $p = 0.5$, and margin of error (d) = 13%, resulting in a minimum sample size of 57 participants. The wider margin of error was selected because of the limited accessible recreational running population during the recruitment period. Although correlation-specific power analysis may provide a more statistically robust estimation for association studies, the Lemeshow formula was used to maintain feasibility within the available population. A total of 57 eligible participants completed all assessments and were included in the final analysis.
The participant recruitment process is summarised in the following STROBE-adapted flow sequence (Figure 1).

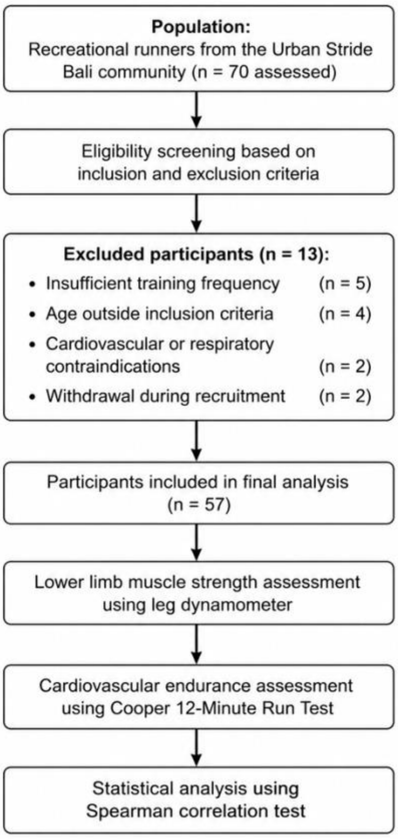

Figure 1. Participant Recruitment and Study Flow Diagram

Lower limb muscle strength was assessed using a calibrated leg dynamometer. Prior to data collection, the instrument underwent routine calibration according to manufacturer recommendations to ensure measurement consistency. Leg dynamometry was selected because of its practicality and previously reported acceptable validity and reliability for lower extremity strength assessment.[13] Participants stood on the dynamometer footplate with the knees slightly flexed and the trunk maintained in an upright position. Following one familiarisation trial, participants performed two maximal isometric pulling efforts lasting approximately 3–5 seconds each with standardised verbal encouragement. The highest value obtained from the two attempts was recorded in kilograms (kg). A one-minute rest interval was provided between attempts to minimise fatigue.

Cardiovascular endurance was evaluated using the Cooper 12-Minute Run Test, a widely used field-based assessment for estimating maximal aerobic capacity.[14] Participants were instructed to cover the greatest possible distance within 12 minutes on a flat standardised running track. Running distance was recorded in metres and converted into estimated maximal oxygen uptake (VO_2max) using the standard Cooper formula. The Cooper Test was selected because of its practicality, low cost, and acceptable correlation with directly measured VO_2max in physically active populations.[14,15] Nevertheless, estimated VO_2max derived from field testing has lower validity than direct cardiopulmonary exercise testing (CPET), and this limitation was considered during interpretation of the findings.

To improve procedural consistency, all measurements were completed within a single testing session. Participants performed a standardised 10–15-minute warm-up consisting of light jogging and dynamic stretching before testing. They were instructed to avoid vigorous exercise within 24 hours before testing and to maintain usual hydration and nutritional intake. However, dietary intake, caffeine consumption, sleep quality, and hydration status were not objectively controlled. A minimum 10-minute seated recovery period was provided between the leg dynamometer assessment and the Cooper Test to minimise residual fatigue. Participants used their habitual running footwear because standardised footwear was unavailable. Running surface and environmental conditions were standardised as much as possible across testing sessions. Participants were also asked regarding previous familiarity with the Cooper Test to reduce learning-related variability.

Several potential confounding variables, including body composition, resistance training history, and training age, were not objectively measured because of resource limitations during field-based data collection. Training intensity was collected through self-reported questionnaire categories (light, moderate, and vigorous), which may introduce subjective reporting bias. Evaluator blinding was not implemented because all assessments were conducted directly during the same testing session.

Data were analysed using IBM SPSS Statistics version 26.0. Descriptive statistics were presented as mean ± standard deviation (SD), median, interquartile range (IQR), minimum–maximum values, frequencies, and percentages where appropriate. Data normality was evaluated using the Shapiro–Wilk test. Because lower limb muscle strength data were not normally distributed ($p < 0.05$), non-parametric analysis was applied. The association between lower limb muscle strength and cardiovascular endurance was analysed using Spearman's rank correlation coefficient (r_s). Correlation strength was interpreted as weak (0.00–0.39), moderate (0.40–0.59), strong (0.60–0.79), or very strong (0.80–1.00). Confidence intervals (95% CI) were additionally calculated to strengthen statistical interpretation. Statistical significance was established at $p < 0.05$.

Potential outliers were screened descriptively through minimum–maximum distribution analysis and visual inspection of data dispersion. No missing or incomplete data were identified because all participants completed the entire measurement protocol. Multivariable regression analysis was not performed because the primary objective of this study was limited to evaluating bivariate association patterns within the available sample size.

Ethical approval was obtained from the Health Research Ethics Commission, Faculty of Medicine, Universitas Udayana/Prof. Dr. I.G.N.G. Ngoerah Hospital, Denpasar, Indonesia (ethical clearance number available on institutional record). All participants provided written informed consent prior to participation. Participant confidentiality and anonymity were maintained throughout the study in accordance with the Declaration of Helsinki.

Discussion

This study demonstrated a very strong positive association between lower limb muscle strength and cardiovascular endurance among recreational runners in Denpasar, Bali ($r_s = 0.833$; $p = 0.001$). Participants with higher leg dynamometer scores generally exhibited higher estimated VO_2max values, indicating that recreational runners with greater lower extremity strength also tended to demonstrate superior aerobic capacity. However, because this study employed a cross-sectional design, the findings should be interpreted as an association rather than evidence of causality.

The observed association may be explained through several physiological and biomechanical mechanisms. Lower limb musculature, particularly the quadriceps, hamstrings, gluteal muscles, gastrocnemius, and soleus, plays an essential role in force generation, propulsion, shock absorption, and postural stabilisation during repetitive running cycles.[5] Stronger lower extremity muscles may improve neuromuscular efficiency and reduce the relative metabolic demand required to sustain running performance, thereby supporting aerobic exercise capacity.[6] Previous studies have shown that resistance-oriented adaptations can enhance motor unit recruitment, muscular oxidative capacity, and movement efficiency during endurance exercise.[7,8],8 These adaptations may partially explain why participants with higher muscular strength also demonstrated higher estimated VO_2max values in the present study.

The findings are consistent with previous investigations reporting beneficial associations between muscular strength and endurance-related performance outcomes. Beattie et al.[7] reported that strength training interventions improved running economy and endurance performance in middle- and long-distance runners without negatively affecting aerobic adaptation. Similarly, Blagrove et al.[8] demonstrated that resistance training may improve neuromuscular performance and biomechanical efficiency in endurance athletes. Nevertheless, most previous studies involved elite or highly trained runners participating in structured conditioning programmes. In contrast, the present study focused on recreational runners with more heterogeneous training backgrounds, thereby providing additional evidence from a population that remains underrepresented in exercise physiology literature, particularly within Southeast Asia.

Despite the strong observed correlation, several confounding variables should be considered when interpreting the findings. Body composition was not objectively measured in this study, although lean muscle mass and adiposity are known to influence both muscular strength and aerobic capacity.[10] Individuals with greater lean body mass may demonstrate superior force production and exercise efficiency, whereas higher adiposity may increase energy expenditure during locomotion and reduce relative VO_2max values. Consequently, the observed relationship between lower limb strength and cardiovascular endurance may partially reflect underlying body composition characteristics rather than an isolated physiological association between the two variables.

Training history and exercise exposure may also have contributed to the strong correlation observed. Participants who regularly engage in higher-intensity running or supplemental resistance training may simultaneously develop greater muscular strength and superior aerobic conditioning.[11] However, resistance-training history, training age, and weekly exercise volume were not comprehensively assessed in this study. Therefore, it remains possible that habitual training behaviour acted as an important confounding factor influencing both variables simultaneously. This consideration is particularly relevant because recreational runners often demonstrate substantial variability in training practices and physical conditioning strategies.

The correlation coefficient observed in this study was relatively high for a field-based cross-sectional investigation. Although this may indicate a meaningful physiological relationship, potential methodological influences should also be acknowledged. The sample consisted of recreational runners from a single running community, which may have introduced self-selection bias. Individuals actively participating in community-based recreational running programmes may already possess higher fitness motivation, better training adherence, or healthier lifestyles than the broader recreational population. Consequently, the homogeneity of physically active participants may have strengthened the observed association between muscular strength and cardiovascular endurance.

Sex-related physiological differences may also influence interpretation of the findings. Males generally possess greater skeletal muscle mass, haemoglobin concentration, and oxygen transport capacity than females, contributing to higher average strength and VO_2max values.[12] Conversely, females may exhibit different fatigue resistance characteristics and substrate utilisation patterns during endurance exercise.[13] Although sex-specific VO_2max categories were applied during classification, subgroup analysis based on sex was not performed because of the relatively limited sample size. Future studies involving larger populations should further evaluate whether the strength–VO_2max association differs according to sex-specific physiological characteristics.

Another important consideration involves the use of the Cooper 12-Minute Run Test as a field-based estimator of aerobic capacity. Although the Cooper Test is widely used because of its practicality and acceptable correlation with laboratory-measured VO_2max,[14,15] it still possesses lower validity than direct cardiopulmonary exercise testing (CPET). Environmental conditions, pacing strategies, participant motivation, and prior familiarity with the test may influence running performance and estimated VO_2max values. In addition, training intensity in this study was obtained through self-reported questionnaires, which may introduce subjective reporting bias. These methodological limitations should be considered when interpreting the magnitude of the observed association.

Theoretical discussion regarding running economy was intentionally interpreted cautiously because running economy was not directly measured in this study. Nevertheless, previous literature suggests that stronger lower limb musculature may contribute to improved movement efficiency and reduced oxygen cost during submaximal running.[8,17] Although these mechanisms cannot be directly confirmed within the present study, they provide plausible physiological explanations supporting the observed association between muscular strength and cardiovascular endurance.

From a clinical and physiotherapy perspective, the present findings may have practical implications for recreational running programmes. Recreational runners frequently prioritise aerobic mileage while underemphasising structured lower extremity strengthening exercises. The strong association identified in this study suggests that maintaining adequate lower limb muscular strength may be relevant for overall aerobic fitness and running performance. However, these findings should not be interpreted as evidence that increasing muscular strength alone will directly improve VO_2max because causal relationships cannot be established within a cross-sectional design. Instead, the results support the potential value of integrating balanced aerobic and resistance-training strategies within recreational conditioning programmes.

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference and does not clarify the temporal direction of the observed association. Second, important confounding variables including body composition, resistance-training history, nutritional intake, hydration status, and sleep quality were not objectively controlled. Third, estimated VO_2max derived from the Cooper Test has lower precision than laboratory-based CPET assessment. Fourth, the sample originated from a single recreational running community, limiting external generalisability to broader recreational runner populations. Finally, subgroup analyses according to sex, training intensity, and age were not conducted because of sample size limitations.

Future studies should employ longitudinal or interventional designs involving larger and more diverse recreational runner populations. Additional measurements including body composition, direct VO_2max assessment, running economy, resistance-training exposure, and multivariable statistical modelling would further clarify the mechanisms underlying the association between muscular strength and cardiovascular endurance in recreational athletes.

Conclusion

This study demonstrated a very strong positive association between lower limb muscle strength and cardiovascular endurance among recreational runners in Denpasar, Bali. Participants with higher lower limb muscle strength generally exhibited higher estimated VO_2max values, indicating that muscular fitness may be an important component associated with aerobic capacity in recreational runners.

These findings highlight the potential relevance of integrating lower extremity strengthening exercises within recreational running programmes to support overall physical fitness and endurance performance. However, because this study used a cross-sectional design, the observed relationship should be interpreted as an association rather than a causal effect.

Future studies are recommended to employ longitudinal or interventional designs involving larger and more diverse recreational runner populations. Additional evaluation of body composition, resistance-training history, running economy, and direct cardiopulmonary exercise testing may provide a more comprehensive understanding of the mechanisms underlying the association between muscular strength and cardiovascular endurance.

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Author Contributions

Dewa Ayu Coming Rahayu: Conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft, writing – review and editing, and visualization.
Sayu Aryantari Putri Thanaya: Supervision, methodology review, writing – review and editing.
M. Widnyana: Supervision, methodological consultation, writing – review and editing.
Anak Ayu Nyoman Trisna Narta Dewi: Validation, academic review, writing – review and editing.

Conflict Of Interest

The authors declare no conflict of interest related to this study.

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Ethical Approval

Ethical approval was obtained from the Health Research Ethics Commission, Faculty of Medicine, Universitas Udayana/Prof. Dr. I.G.N.G. Ngoerah Hospital, Denpasar, Indonesia. All participants provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki.

Data Availability

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

References

1. Larassary A. Perspektif pengalaman konsumen terhadap kesuksesan event lari Borobudur Marathon 2019. JUARA J Olahraga. 2020;5(2):163-174.
2. Gordon D, Wightman S, Basevitch I, Johnstone J, Espejo-Sanchez C, Beckford C, et al. Physiological and training characteristics of recreational marathon runners. Open Access J Sports Med. 2017;8:231-241.
3. Martinez MW, Kim JH, Shah AB, Phelan D, Emery MS, Wasfy MM, et al. Exercise-induced cardiovascular adaptations and approach to exercise and cardiovascular disease. J Am Coll Cardiol. 2021;78(14):1453-1470.
4. Charkot J, Bieńkowski W, Kusy B, Bieńkowski M, Charkot M, Kucharczyk P, et al. The impact of maximal oxygen uptake (VO2max) on athletic performance and health: a review. Qual Sport. 2025;43:61293.
5. Widiawati P. VO2max on women recreation runners: case study on women's recreation runners in Gantarvelocity. J Sport Sci. 2020;10(2):129-134.
6. Prieto-González P, Sedlacek J. Effects of running-specific strength training, endurance training, and concurrent training on recreational endurance athletes' performance and selected anthropometric parameters. Int J Environ Res Public Health. 2022;19(17):10773.
7. Beattie K, Carson BP, Lyons M, Rossiter A, Kenny IC. The effect of strength training on performance indicators in distance runners. J Strength Cond Res. 2017;31(1):9-23.
8. Blagrove RC, Howatson G, Hayes PR. Effects of strength training on the physiological determinants of middle- and long-distance running performance: a systematic review. Sports Med. 2018;48(5):1117-1149.
9. Llanos-Lagos C, Ramirez-Campillo R, Moran J, Sáez de Villarreal E. Effect of strength training programs in middle- and long-distance runners' economy at different running speeds: a systematic review with meta-analysis. Sports Med. 2024;54(4):895-932.
10. Crowley E, Powell C, Carson BP, Davies RW. The effect of exercise training intensity on VO2max in healthy adults: an overview of systematic reviews and meta-analyses. Transl Sports Med. 2022;2022(1):9310710.

11. Kakouris N, Yener N, Fong DTP. A systematic review of running-related musculoskeletal injuries in runners. J Sport Health Sci. 2021;10(5):513-522.
12. Mwebaze N, Makubuya T, Kamwebaze M, Mwase M, Ojara RR, Opio P, et al. Physiological sex differences in response to exercise. Turk J Kinesiol. 2025;11(4):241-249.
13. Fauziah E, Zulfah K, Oktaviani YE. Penatalaksanaan fisioterapi untuk meningkatkan keseimbangan dinamis lansia dengan teknik core stability exercise dan tandem walking exercise. Fisiomu. 2022;3(1):16-22.
14. Ceolin-Nascimento R, Cepeda FX, DeMoura JR, Camargo FCF, Fortes-Queiroz L, Ferreira FG, et al. Agreement between ACSM's equation and cardiopulmonary exercise test in determine maximal oxygen uptake in individuals with metabolic syndrome. FASEB J. 2020;34(Suppl 1):1.
15. Penry JT, Wilcox AR, Yun J. Validity and reliability analysis of Cooper's 12-minute run and the multistage shuttle run in healthy adults. J Strength Cond Res. 2011;25(3):597-605.
16. Alvero-Cruz JR, Carnero EA, Giráldez García MA, Alacid F, Rosemann T, Nikolaidis PT, et al. Cooper test provides better half-marathon performance prediction in recreational runners than laboratory tests. Front Physiol. 2019;10:1349.
17. Bayissa M, Haile D, Afework D, Jebessa G, Mooses K, Mooses M. Association between running economy and VO2max values in high-level Ethiopian male and female distance runners measured at high altitude. BMC Res Notes. 2025;18(1):319.