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The Relationship Between Exercise Intensity and Cardiovascular Health

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Abstract
The prevalence of cardiovascular diseases among adolescents has increased significantly in recent years, necessitating interventions that promote cardiovascular health. This study aimed to examine the relationship between exercise intensity and cardiovascular health parameters in adolescents enrolled at the Faculty of Physical Education and Sports Science (FIKK) at Universitas Negeri Makassar (UNM). A cross-sectional study was conducted with 125 adolescent participants (15-18 years old) from March to August 2024. Cardiovascular health was assessed through measurements of resting heart rate (RHR), blood pressure, maximum oxygen uptake (VO_2max), and pulse rate recovery (PRR) after graded exercise testing. Exercise intensity was categorized into three levels: low, moderate, and high based on percentage of maximum heart rate (HRmax). Results demonstrated a significant inverse relationship between exercise intensity and resting heart rate ($p < 0.05$), with participants engaging in high-intensity exercise exhibiting lower RHR values (M = 58.2 bpm, SD = 4.8) compared to low-intensity exercisers (M = 72.5 bpm, SD = 6.2). Additionally, VO_2max showed significant positive correlation with exercise intensity ($r = 0.687$, $p < 0.001$). Blood pressure measurements indicated that moderate to high-intensity exercise participants demonstrated better cardiovascular efficiency with lower systolic and diastolic pressures. Pulse rate recovery at one minute post-exercise was significantly faster in the high-intensity group (M = 22.8 bpm recovery, SD = 3.5) compared to the low-intensity group (M = 10.5 bpm recovery, SD = 4.1). These findings suggest that appropriate exercise intensity levels, particularly moderate to high-intensity training, are associated with improved cardiovascular health markers in adolescents. Implications for cardiovascular health promotion programs in educational institutions are discussed.

Keywords: exercise intensity, cardiovascular health, adolescents, VO_2max, resting heart rate

INTRODUCTION

Cardiovascular disease (CVD) remains one of the leading causes of morbidity and mortality worldwide, accounting for approximately 17.9 million deaths annually according to the World Health Organization (WHO). While these conditions have traditionally been associated with adult populations, emerging epidemiological evidence indicates an alarming trend of cardiovascular risk factors appearing increasingly among adolescent and young adult populations (Catapano et al., 2016). The development of atherosclerosis and other cardiovascular pathologies often begins during adolescence, making early intervention during this critical developmental period essential for long-term health outcomes (Berenson et al., 2018).

In Indonesia, the burden of non-communicable diseases, including cardiovascular conditions, has increased substantially over the past two decades. According to data from the Indonesian Health Survey (Survei Kesehatan Indonesia), the prevalence of hypertension in adolescents aged 15-24 years has risen from 3.2% in 2013 to 7.8% in 2023. This upward trend corresponds with decreased physical activity levels among young Indonesians, with only 33.5% of adolescents meeting the World Health Organization's recommendation of at least 60 minutes of moderate-intensity physical activity daily

(Kementerian Kesehatan RI, 2023). The sedentary lifestyle patterns observed in contemporary adolescent populations, amplified by increased screen time and reduced participation in structured physical education and sports programs, have created a concerning public health scenario.

The Faculty of Physical Education and Sports Science (FIKK) at Universitas Negeri Makassar (UNM) serves as an important institution for training future physical education professionals and promoting sports science research in Eastern Indonesia. However, limited evidence exists regarding the cardiovascular health profiles of students within this institution and their relationship to the intensity of physical exercise undertaken. Despite the theoretical expectation that students enrolled in a faculty dedicated to physical education would demonstrate superior cardiovascular health markers, recent observations suggest variable cardiovascular fitness levels among this population, likely reflecting differences in individual exercise habits and training intensity.

The relationship between physical exercise intensity and cardiovascular health has been extensively studied in international literature, with consistent evidence demonstrating that structured, progressively challenging exercise programs lead to significant improvements in cardiovascular function (Garber et al., 2011). The cardiovascular system responds to training stimuli through a series of adaptive mechanisms including improved cardiac output, enhanced vascular function, reduced peripheral vascular resistance, and improved myocardial efficiency (Cornelissen & Smart, 2013). These adaptations manifest as measurable improvements in clinical cardiovascular parameters including resting heart rate (RHR), blood pressure (BP), maximal oxygen uptake (VO_2max), and post-exercise heart rate recovery (PHRR) (Kambis & Kambis, 2017).

Resting heart rate, defined as the number of heart beats per minute in a calm, post-awakening state, represents one of the most accessible and clinically relevant indicators of cardiovascular fitness and overall health status. Longitudinal epidemiological studies have demonstrated that elevated resting heart rate is an independent predictor of cardiovascular mortality and all-cause mortality, with each 5 bpm increase in resting heart rate associated with a 15-20% increase in mortality risk (Cole et al., 2019). Regular physical training, particularly aerobic exercise of moderate to high intensity, has been shown to reduce resting heart rate by 5-10 bpm in previously sedentary individuals, reflecting improved vagal tone and enhanced cardiac efficiency (Huang & Sesso, 2020).

Blood pressure regulation is another critical parameter influenced by exercise intensity. The pathophysiology of exercise-induced blood pressure reduction involves multiple mechanisms including endothelial function improvement, sympathetic nervous system downregulation, enhanced nitric oxide bioavailability, and favorable changes in vascular structure (Montero et al., 2014). Meta-analytic reviews have consistently demonstrated that aerobic exercise programs of moderate intensity (50-70% of maximum heart rate) sustained over 8-16 weeks produce reductions in both systolic and diastolic blood pressure averaging 4-6 mmHg and 3-4 mmHg respectively, effects comparable to single-agent antihypertensive pharmacotherapy (Pescatello et al., 2015).

Maximal oxygen uptake (VO_2max), expressed as milliliters of oxygen consumed per kilogram of body weight per minute (ml/kg/min), represents the gold standard marker of cardiovascular fitness and aerobic exercise capacity. This parameter reflects the integrated function of the respiratory system, cardiovascular system, and skeletal muscle oxidative capacity. Research has consistently demonstrated dose-response relationships between exercise intensity and VO_2max improvements, with high-intensity interval training producing VO_2max gains of 15-25% over 8-12 week periods, substantially greater than improvements achieved through continuous moderate-intensity exercise (Weston et al., 2016). Furthermore, VO_2max demonstrates strong inverse associations with all-cause mortality and cardiovascular mortality risk, with each 1 ml/kg/min increase in VO_2max associated with approximately 10% reduction in mortality risk (Kokkinos et al., 2018).

Post-exercise heart rate recovery, defined as the rate of decline in heart rate during recovery from exercise, serves as an independent predictor of cardiovascular health and mortality risk. The physiological basis for the prognostic significance of heart rate recovery relates to parasympathetic nervous system reactivation and baroreceptor sensitivity. Blunted heart rate recovery following exercise testing has been associated with autonomic nervous system dysfunction, endothelial dysfunction, and increased cardiovascular mortality risk (Cole et al., 1999). Systematic training programs emphasizing higher exercise intensities enhance vagal tone and accelerate parasympathetic reactivation, resulting in improved post-exercise heart rate recovery kinetics.

Despite the extensive international evidence base documenting the cardiovascular benefits of exercise, significant gaps exist in understanding how these relationships manifest in specific populations, particularly in Indonesian adolescent populations. The generalizability of exercise-cardiovascular health relationships to diverse ethnic populations, geographic regions, and institutional contexts remains an important research question. Furthermore, optimal exercise intensity prescriptions may vary based on individual characteristics including age, sex, baseline fitness level, and genetic predisposition.

The primary aim of this investigation was to comprehensively evaluate the relationship between exercise intensity and multiple indicators of cardiovascular health in adolescent students at FIKK UNM. We hypothesized that adolescents engaging in higher-intensity exercise training would demonstrate superior cardiovascular health parameters including lower resting heart rate, improved blood pressure profile, enhanced VO_2max, and faster post-exercise heart rate recovery compared to peers engaging in lower-intensity exercise. Understanding these relationships in the Indonesian context will provide evidence to guide cardiovascular health promotion initiatives within educational institutions and contribute to the broader evidence base on exercise prescription for adolescent populations.

METHODS

This investigation utilized a cross-sectional comparative research design to examine associations between exercise intensity and cardiovascular health parameters among adolescent students. The study was conducted over a six-month period from March to August 2024 at the Faculty of Physical Education and Sports Science (FIKK), Universitas Negeri Makassar (UNM), located in Makassar, South Sulawesi Province, Indonesia.

The study population consisted of adolescent students aged 15-18 years enrolled in degree programs at FIKK UNM during the 2023-2024 academic year. A stratified random sampling procedure was employed to recruit 125 participants (67 males, 58 females) from the total enrolled student population. Inclusion criteria specified that participants must have been enrolled in formal physical education training programs, possess documented health clearance for exercise testing, and demonstrate regular participation in structured physical activity for a minimum of six months prior to study enrollment. Exclusion criteria comprised the following: presence of cardiopulmonary disease or significant cardiac arrhythmia, uncontrolled hypertension (≥160/100 mmHg), current use of cardiovascular medications, pregnancy (for female participants), recent myocardial infarction or stroke within the preceding year, or inability to perform maximal exercise testing due to musculoskeletal limitations.

Demographic information including age, sex, body weight (kg), height (cm), and self-reported physical activity history was collected via standardized questionnaire administration. Body mass index (BMI) was calculated as weight (kg) divided by height in meters squared (m^2). All participants completed a comprehensive health screening form and provided written informed consent prior to study participation. For participants under 18 years of age, additional informed consent was obtained from a parent or legal guardian in accordance with institutional research ethics protocols.

Cardiovascular measurements were obtained following standardized procedures conducted in a temperature-controlled laboratory environment (22-24°C) between 07:00 and 09:00 hours on each testing day. Following a 10-minute seated rest period, resting heart rate was measured via pulse palpation over 60 seconds, with values recorded in beats per minute (bpm). Blood pressure was assessed using a calibrated mercury sphygmomanometer with appropriate cuff sizing according to arm circumference, with systolic and diastolic pressures recorded in millimeters of mercury (mmHg). Mean arterial pressure (MAP) was calculated using the formula: $MAP = [Systolic + 2(Diastolic)] / 3$.

Maximal oxygen uptake (VO_2max) was assessed utilizing a graded exercise test (GXT) protocol on a calibrated treadmill ergometer (Woodway Pro XL, Woodway USA, Inc.) with simultaneous breath-by-breath measurement of expired gases via open-circuit indirect calorimetry (MetaMax 3B, Cortex Biophysics GmbH, Leipzig, Germany). The GXT protocol commenced at an initial speed of 2.5 km/hour with 0% grade, with speed incrementally increasing by 0.5 km/hour every 30 seconds and grade incrementally increasing by 1% every minute until either volitional exhaustion was achieved or objective criteria for test termination were met. Heart rate was monitored continuously throughout exercise testing using 12-lead electrocardiography, with measurements recorded every 30 seconds. Borg rate of perceived exertion (RPE) was assessed at each exercise stage using the 6-20 point scale. VO_2max was defined as the highest oxygen uptake measured during the final 30 seconds of maximal exercise testing.

Following exercise testing, participants were instructed to remain standing while heart rate was monitored at 1 minute and 5 minutes post-exercise. Heart rate recovery at 1 minute (HRR_1) was calculated as the difference between peak heart rate during exercise and heart rate at 1 minute recovery, with values expressed as beats per minute. Similarly, heart rate recovery at 5 minutes (HRR_5) was calculated using the same methodology.

Exercise intensity was assessed via individual self-report questionnaire regarding typical intensity of training undertaken during structured exercise sessions. Participants were asked to characterize their habitual exercise intensity across all physical activities undertaken within the preceding three months, with specific guidance provided regarding intensity definitions. Low-intensity exercise was defined as activity performed at 50-60% of maximum heart rate (HRmax) with sustained ability to converse. Moderate-intensity exercise was characterized as activity performed at 60-75% of HRmax with difficulty sustaining conversation. High-intensity exercise was defined as activity performed at 75-90% of HRmax with inability to sustain conversation. Classification into intensity categories was confirmed through actigraph accelerometer data (ActiGraph wGT3X-BT, Pensacola, Florida) worn during a representative 7-day period. Triaxial accelerometer counts were converted to intensity categories using established cut-points for adolescent populations.

Statistical analyses were performed using SPSS version 26.0 (IBM Corporation, Armonk, New York) and GraphPad Prism version 9.0 (GraphPad Software, La Jolla, California). Descriptive statistics including means, standard deviations, and frequency distributions were calculated for all variables. Analysis of variance (ANOVA) with post-hoc Tukey HSD testing was employed to compare cardiovascular parameters across exercise intensity categories. Pearson product-moment correlation coefficients were calculated to assess associations between continuous measures of exercise intensity and cardiovascular parameters. Multiple linear regression analyses were conducted with cardiovascular parameters as dependent variables and exercise intensity along with covariates (age, sex, BMI) as independent variables. Statistical significance was established at $p < 0.05$ (two-tailed). Assumptions for parametric testing including normality and homogeneity of variance were assessed via Shapiro-Wilk and Levene tests respectively.

RESULT AND DISCUSSION

The study cohort comprised 125 adolescent participants with mean age of 16.8 ± 1.2 years, with females representing 46.4% of the sample. Mean body weight was 62.3 ± 8.7 kg with mean height of 166.2 ± 7.8 cm, yielding mean BMI of 22.5 ± 3.1 kg/m². Participants were categorized into exercise intensity groups based on their habitual exercise practices: low-intensity group (n = 38, 30.4%), moderate-intensity group (n = 51, 40.8%), and high-intensity group (n = 36, 28.8%). No significant differences in demographic characteristics including age, sex distribution, body weight, height, or BMI were observed across exercise intensity groups ($p > 0.05$ for all comparisons), supporting the validity of group comparisons.

Resting heart rate demonstrated substantial variation across exercise intensity groups, with statistically significant between-group differences detected via ANOVA ($F_{2,122} = 38.7$, $p < 0.001$). The low-intensity group exhibited mean resting heart rate of 72.5 ± 6.2 bpm, which was substantially elevated compared to the moderate-intensity group (M = 64.8 ± 5.1 bpm) and high-intensity group (M = 58.2 ± 4.8 bpm). Post-hoc Tukey HSD testing revealed significant pairwise differences between all three groups ($p < 0.05$ for all comparisons). The reduction in resting heart rate observed in high-intensity versus low-intensity exercisers represented a difference of 14.3 bpm, which exceeds the clinically meaningful threshold. Pearson correlation analysis revealed a significant inverse relationship between exercise intensity (continuous scale) and resting heart rate ($r = -0.684$, $p < 0.001$), indicating that as exercise intensity increased, resting heart rate decreased proportionally. These findings align with extensive prior research documenting the cardiovascular training effects on autonomic nervous system function. Regular high-intensity exercise promotes increased parasympathetic tone and enhanced vagal tone, resulting in decreased resting sympathetic activity and consequently reduced resting heart rate (Huang & Sesso, 2020). The substantial reduction in resting heart rate observed in the current investigation is consistent with longitudinal studies demonstrating 5-10 bpm reductions following sustained aerobic training programs of 8-16 weeks duration.

Blood pressure measurements revealed clinically important differences across exercise intensity groups. Systolic blood pressure demonstrated significant between-group variation ($F_{2,122} = 19.4$, $p < 0.001$), with low-intensity exercisers exhibiting higher systolic pressures (M = 128.6 ± 8.3 mmHg) compared to moderate-intensity (M = 122.4 ± 7.1 mmHg) and high-intensity exercisers (M = 116.8 ± 6.4 mmHg). Similarly, diastolic blood pressure differed significantly across groups ($F_{2,122} = 16.8$, $p < 0.001$), with low-intensity participants demonstrating higher diastolic values (M = 82.7 ± 6.5 mmHg) compared to high-intensity participants (M = 75.2 ± 5.8 mmHg). Mean arterial pressure, representing a more integrated assessment of blood pressure burden, also demonstrated significant reductions with increasing exercise intensity ($F_{2,122} = 21.3$, $p < 0.001$), declining from 94.7 ± 6.8 mmHg in low-intensity to 89.1 ± 5.2 mmHg in high-intensity exercisers. The magnitude of systolic pressure difference (11.8 mmHg) between low and high-intensity groups exceeds typical clinical antihypertensive medication effects and approaches the blood pressure benefits documented in systematic reviews of aerobic exercise interventions. The blood pressure findings of this investigation are consistent with established physiological mechanisms through which exercise improves vascular function and reduces peripheral resistance. Regular exercise enhances endothelial function through increased nitric oxide bioavailability, reduces vascular inflammation, and promotes favorable vascular remodeling with improved compliance (Montero et al., 2014). Additionally, exercise reduces sympathetic nervous system activation and enhances parasympathetic tone, both contributing to lower resting blood pressure. The inverse relationship between exercise intensity and blood pressure suggests dose-dependent effects of training, with higher intensities producing greater cardiovascular benefits.

Maximal oxygen uptake demonstrated the most dramatic differences across exercise intensity groups, with highly significant between-group variation detected ($F_{2,122} = 67.9$, $p < 0.001$). Low-intensity exercisers exhibited mean VO_2max of 35.2 ± 4.8 ml/kg/min, which was substantially lower than moderate-intensity exercisers (M = 42.7 ± 5.3 ml/kg/min) and high-intensity exercisers (M = 52.1 ± 6.4 ml/kg/min). The 16.9 ml/kg/min difference between low and high-intensity groups represents a 48% improvement in maximal aerobic capacity, demonstrating the substantial physiological adaptations achieved through higher-intensity training. Pearson correlation analysis revealed a strong positive correlation between exercise intensity and VO_2max ($r = 0.687$, $p < 0.001$), indicating substantial proportional improvements in aerobic capacity with increasing exercise intensity. Multiple linear regression analysis controlling for age, sex, and BMI confirmed that exercise intensity remained a significant independent predictor of VO_2max ($\beta = 8.35$, $p < 0.001$), with each unit increase in exercise intensity associated with 8.35 ml/kg/min improvement in VO_2max. The substantial improvements in VO_2max associated with high-intensity training are consistent with both acute and chronic adaptation responses of the cardiovascular and respiratory systems to training stimuli (Weston et al., 2016). High-intensity exercise stimulates mitochondrial biogenesis, promotes capillarization and increased oxygen diffusion capacity, enhances cardiac output through both increased stroke volume and heart rate responses, and improves skeletal muscle oxidative enzyme activity. These adaptations collectively increase the body's capacity to extract, transport, and utilize oxygen during maximal exercise effort. The VO_2max values observed in the high-intensity group (52.1 ml/kg/min) are comparable to values documented in athletic populations and exceed age-adjusted normative values by approximately 30-40%, indicating superior cardiovascular fitness in this subgroup.

Post-exercise heart rate recovery at 1 minute (HRR_1) differed significantly across exercise intensity groups ($F_{2,122} = 48.2$, $p < 0.001$), with high-intensity exercisers demonstrating faster recovery

(M = 22.8 ± 3.5 bpm recovery) compared to moderate-intensity (M = 16.4 ± 3.8 bpm recovery) and low-intensity exercisers (M = 10.5 ± 4.1 bpm recovery). Similarly, heart rate recovery at 5 minutes (HRR_5) demonstrated significant between-group differences ($F_{2,122} = 42.7$, $p < 0.001$), with high-intensity exercisers exhibiting faster recovery (M = 38.6 ± 5.2 bpm recovery) compared to low-intensity exercisers (M = 26.2 ± 5.8 bpm recovery). The enhanced heart rate recovery observed in high-intensity trained individuals reflects improved parasympathetic nervous system function and enhanced baroreceptor sensitivity. The physiological mechanism underlying the superior heart rate recovery in high-intensity trained individuals involves increased vagal reactivation and enhanced parasympathetic tone during recovery phases. High-intensity interval training specifically promotes autonomic nervous system adaptations that preferentially enhance parasympathetic dominance, facilitating more rapid post-exercise deceleration of heart rate. The prognostic significance of enhanced heart rate recovery is substantial, with prior investigations demonstrating that impaired heart rate recovery predicts cardiovascular mortality and all-cause mortality independent of exercise capacity and resting heart rate. Thus, the enhanced post-exercise heart rate recovery observed in high-intensity training participants represents an important indicator of improved cardiovascular health and autonomic nervous system function (Cole et al., 1999).

Sex-stratified analyses revealed that the relationship between exercise intensity and cardiovascular parameters did not significantly differ between males and females ($p > 0.05$ for interaction terms), suggesting that the cardiovascular training benefits of higher-intensity exercise apply equally to both sexes in this adolescent population. However, absolute values of certain parameters differed between sexes in expected directions, with males demonstrating higher absolute VO_2max values and lower resting heart rates compared to females, consistent with known sex differences in cardiovascular physiology. The absence of significant sex interactions suggests that exercise intensity prescriptions for cardiovascular health improvement can be applied universally within adolescent populations without sex-based modifications.

The findings of this investigation have several important implications for understanding cardiovascular health promotion among adolescents in Indonesian educational contexts. The substantial cardiovascular benefits observed with higher-intensity exercise training provide evidence supporting the incorporation of higher-intensity exercise components into school-based physical education programs and university-level sports science curricula. Current guidelines from the World Health Organization recommend that adolescents participate in at least 60 minutes of moderate-intensity physical activity daily, with additional benefits accruing from vigorous-intensity activities conducted at least three days weekly. The results of this investigation suggest that progressive implementation of higher-intensity training components may yield meaningful cardiovascular health benefits and contribute to the prevention of cardiovascular disease in this population. Furthermore, the marked cardiovascular fitness differences observed between intensity categories suggest that regular monitoring of cardiovascular parameters including resting heart rate and blood pressure could serve as useful outcome measures for physical education program evaluation.

CONCLUSSION

This investigation comprehensively evaluated the relationship between exercise intensity and cardiovascular health in adolescent students at the Faculty of Physical Education and Sports Science at Universitas Negeri Makassar. The findings provide compelling evidence that adolescents engaging in higher-intensity exercise training demonstrate substantially superior cardiovascular health parameters compared to peers engaged in lower-intensity exercise. Specifically, high-intensity exercise participants demonstrated significantly lower resting heart rates (58.2 versus 72.5 bpm), reduced blood pressure measurements (systolic: 116.8 versus 128.6 mmHg), enhanced maximal oxygen uptake capacity (52.1 versus 35.2 ml/kg/min), and faster post-exercise heart rate recovery (22.8 versus 10.5 bpm at 1 minute post-exercise) compared to low-intensity exercisers. These cardiovascular adaptations represent meaningful improvements in multiple indicators of cardiovascular health and fitness, with substantial clinical significance for long-term health outcomes and mortality risk reduction.

The mechanisms underlying these superior cardiovascular outcomes with higher-intensity training involve multiple physiological adaptations including enhanced autonomic nervous system function with increased parasympathetic tone, improved endothelial function and vascular compliance, beneficial remodeling of cardiac structure and function, enhanced skeletal muscle oxidative capacity and mitochondrial function, and favorable hemodynamic adaptations. These mechanisms operate in concert to produce the clinically meaningful improvements in cardiovascular parameters documented in the current investigation. The strong dose-response relationships observed between exercise intensity and cardiovascular parameters suggest that even incremental increases in exercise intensity produce measurable cardiovascular benefits.

Based on these findings, we formulate the following recommendations for future practice and research:

First, we recommend that physical education programs within Indonesian secondary schools and universities systematically incorporate higher-intensity exercise components into their curricula, with careful progression and appropriate safety monitoring. The substantial cardiovascular health benefits observed with high-intensity training provide evidence supporting such programmatic modifications, particularly given the documented increases in cardiovascular risk factors among Indonesian adolescents. Implementation should emphasize proper warm-up procedures, appropriate exercise progression, and adequate recovery between high-intensity efforts to minimize injury risk while maximizing health benefits.

Second, we recommend that schools and universities establish routine cardiovascular screening protocols for adolescent populations, incorporating assessment of resting heart rate and blood pressure as accessible, low-cost indicators of cardiovascular health status. Such screening could guide identification of adolescents demonstrating elevated cardiovascular risk and target them for more intensive intervention programs. Furthermore, periodic reassessment of these parameters could serve to motivate students and document program effectiveness.

Third, we recommend that future research extend this investigation through longitudinal designs implementing randomized controlled trials of structured exercise intensity interventions. Such designs would enable documentation of cardiovascular adaptations occurring over time with progressive training and would permit assessment of which exercise intensities optimize health benefits while maintaining participant adherence and safety. Multi-site investigations incorporating diverse Indonesian populations would strengthen the evidence base for exercise prescription guidelines applicable to Indonesian adolescents.

Fourth, we recommend investigation of potential moderating factors that may influence the exercise intensity-cardiovascular health relationship, including genetic predisposition, dietary patterns, socioeconomic status, and psychological factors including stress and depression. Understanding how these factors interact with exercise training could enable more individualized exercise prescription approaches.

Fifth, we recommend development and implementation of community-based physical activity promotion programs targeting broader adolescent populations beyond academic institutions, given the concerning population-level data regarding low physical activity rates among Indonesian youth. Such programs should incorporate evidence-based high-intensity exercise components while addressing barriers to participation including access, transportation, and social support.

In conclusion, the current investigation provides important evidence demonstrating that exercise intensity represents a critical determinant of cardiovascular health in adolescent populations. These findings underscore the importance of exercise prescription incorporating appropriate intensity progression for cardiovascular health promotion. Implementation of these evidence-based recommendations could contribute meaningfully to addressing the rising burden of cardiovascular disease and associated risk factors in Indonesian adolescent populations, promoting healthier developmental trajectories and enhanced long-term health outcomes. Future research investigating mechanisms of exercise-induced cardiovascular adaptations and identifying optimal intensity prescriptions for diverse adolescent populations will continue to advance the evidence base for cardiovascular health promotion through physical activity.

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