



Sex-Specific Effects of Resistance Training Intensity on High-Density Lipoprotein Cholesterol in Aging Adults

Intan Suraya Ellyas¹, Abdelhalim Yousef², Carla Mariela Salazar-Ayala³

¹Department of Sport Science, Sebelas Maret University, Surakarta, Indonesia

²Department of Sport Health Science, University of Sadat City, Sadat City, Egypt

³Department of Physical Education and Sport Science, Universidad Autónoma de Chihuahua, Chihuahua, Mexico

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ABSTRACT

Purpose of the study: This study aims to examine the effects of light and moderate resistance training intensities on high-density lipoprotein (HDL) cholesterol levels in aging adults, compare sex differences in HDL cholesterol responses, and analyze whether sex modifies the relationship between training intensity and lipid adaptation.

Methodology: This study employed a quasi-experimental 2×2 factorial design involving adults aged 45–75 years from the Senam Sehat Indonesia (SSI) PWRI group in Karangpandan, Indonesia. Participants underwent eight weeks of light- or moderate-intensity resistance training. HDL cholesterol was assessed through blood analysis, and changes were evaluated using two-way ANOVA following normality and homogeneity assumption testing.

Main Findings: Both light and moderate resistance training were associated with increased HDL cholesterol levels, with no significant difference between training intensities ($p = 0.769$). Female participants showed a higher average HDL improvement than male participants at the descriptive level; however, this sex difference did not reach statistical significance ($p = 0.187$), despite a medium effect size ($\eta^2 = 0.06$), indicating that the study was likely underpowered to detect it. No significant interaction was found between training intensity and sex ($p = 0.482$).

Novelty/Originality of this study: Rather than assuming a uniform physiological response, this study explored whether biological sex influences lipid adaptation following resistance training. Although the sex-related effect was not statistically significant, the observed medium effect size highlights potential biological differences in HDL responses. These findings emphasize the importance of adequately powered sex-stratified trials and provide effect-size estimates to support future research design.

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Corresponding Author:

Intan Suraya Ellyas,

Department of Sport Science, Faculty of Sports, Sebelas Maret University, Jl. Ir. Sutami No. 36, Kentingan, Surakarta 57126, Indonesia.

Email: surayaellyas@gmail.com

1. INTRODUCTION

Cardiovascular disease (CVD) represents the leading contributor to premature mortality worldwide, accounting for approximately 30% of all deaths in 2005, with the World Health Organization projecting a further increase in CVD-related mortality during subsequent years [1], [2]. In Indonesia, cardiovascular disease remains a major public health concern, with data from the National Household Health Survey identifying coronary heart disease as responsible for 26.4% of all deaths and estimating substantial mortality rates attributable to this

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condition [3], [4]. The increasing burden of CVD is driven by multiple interacting risk factors, among which dyslipidemia, characterized by elevated low-density lipoprotein (LDL), reduced high-density lipoprotein (HDL), and increased triglyceride concentrations, plays a central role in the development and progression of atherosclerosis [5]–[7].

High-density lipoprotein (HDL) cholesterol, commonly recognized as “good cholesterol,” contributes to cardiovascular protection through reverse cholesterol transport, a physiological process that removes excess cholesterol from peripheral tissues and arterial walls and transports it back to the liver for metabolism and elimination [8]–[11]. Previous evidence indicates that each 1 mg/dL increase in HDL cholesterol is associated with a reduction in cardiovascular event risk of approximately 2–3% in men and 3–4% in women [12], [13]. However, despite its cardioprotective role, inadequate HDL levels remain common among Indonesian adults, particularly within aging populations, creating an urgent need for accessible and sustainable interventions to improve cardiovascular health [14]–[17].

Physical exercise, particularly resistance training, has received increasing attention as an effective non-pharmacological approach for improving lipid profiles and reducing cardiovascular risk among older adults [18]–[21]. The physiological mechanisms underlying the lipid-modifying effects of resistance training are associated with progressive muscular loading, activation of lipoprotein lipase (LPL) and hepatic lipase (HL), and improvements in lipoprotein remodelling and HDL particle maturation [22]–[25]. Furthermore, resistance training promotes increased fatty acid oxidation during post-exercise recovery, stimulates reverse cholesterol transport pathways, and supports the formation of apolipoprotein A-I-containing HDL particles [26], [27].

Despite these established benefits, important questions remain regarding the optimal prescription of resistance training for improving HDL cholesterol among ageing populations. Training intensity represents a particularly important but insufficiently studied factor because older adults often have physiological limitations that may restrict participation in high-intensity exercise protocols [28]–[30]. Although major exercise medicine organisations recommend resistance training as part of cardiovascular risk reduction strategies, current guidelines provide limited specificity regarding the intensity required to maximise HDL improvement [31], [32]. In addition, biological sex may influence HDL adaptation following exercise because males and females demonstrate differences in lipid metabolism, hormonal regulation, hepatic lipase activity, and apolipoprotein A-I production [31]–[34]. Therefore, the possibility that males and females respond differently to the same resistance training stimulus requires further investigation.

Previous studies have provided valuable insights but also reveal important methodological limitations. Pourmontaseri et al. [26] demonstrated that exercise interventions improve lipid profiles, including HDL cholesterol; however, their systematic review and meta-analysis focused mainly on aerobic and mixed exercise interventions and provided limited evidence regarding resistance training intensity effects among older adults. Similarly, Żukowiecka-Séga et al. [19] highlighted the potential role of resistance training as a non-pharmacological strategy for chronic disease management but identified limited evidence regarding age-specific exercise prescriptions and direct comparisons of training intensity.

Research examining sex differences in lipid metabolism has also demonstrated important biological variations. Masuda et al. [8] reported sex-specific differences in plasma lipoprotein subclasses among middle-aged and older adults; however, the observational design did not evaluate exercise-induced lipid adaptations. Vladimirov et al. [38] further demonstrated distinct cholesterol metabolism patterns between males and females, supporting the biological plausibility of sex-dependent responses to exercise, although the interaction between biological sex and resistance training intensity remains unclear.

The American Heart Association scientific statement recognised resistance training as an important cardiovascular risk-reduction strategy but acknowledged insufficient evidence regarding optimal intensity parameters for improving specific lipid outcomes, including HDL cholesterol [31]. Dores et al. [32] similarly reported that resistance exercise prescriptions for cardiovascular benefits remain underutilized and require more precise evidence to guide intensity selection. Collectively, previous research has established the importance of exercise for cardiovascular health but has not adequately addressed whether resistance training intensity produces different HDL responses in ageing adults or whether these responses are modified by biological sex.

This unresolved question represents a significant research gap, particularly within community-based older adult populations in Indonesia. The Senam Sehat Indonesia (SSI) PWRI group in Karangpandan, Karanganyar, provides an ecologically relevant setting for investigating this issue because it includes middle-aged and older adults of both sexes participating in structured community exercise activities. Understanding how training intensity and sex influence HDL adaptation may support the development of safer, more effective, and more personalized exercise recommendations for cardiovascular risk management in aging populations.

The novelty of this study lies in applying a 2×2 factorial experimental design to simultaneously examine the effects of resistance training intensity and biological sex on HDL cholesterol changes among older Indonesian adults. Unlike previous studies that have generally investigated exercise effects without directly analysing the interaction between training intensity and sex, this study evaluates whether sex modifies the relationship between resistance training intensity and HDL adaptation. The findings are expected to provide practical evidence for

designing intensity-appropriate and sex-sensitive resistance training programmes for cardiovascular health promotion.

Therefore, this study aimed to answer three interrelated research questions: (1) Does training intensity (light versus moderate) differentially affect HDL cholesterol elevation in older adults? (2) Do males and females demonstrate different HDL responses following resistance training? and (3) Is there an interaction between training intensity and sex on HDL cholesterol outcomes?.

2. RESEARCH METHOD

2.1 Research Design

This study employed a quasi-experimental research design using a 2×2 factorial approach. The factorial design combined two levels of resistance training intensity light intensity (A1: 40–60% 1RM) and moderate intensity (A2: 60–75% 1RM) with two categories of biological sex, namely male (B1) and female (B2), resulting in four experimental cells: A1B1, A1B2, A2B1, and A2B2. This design enabled simultaneous examination of the main effects of training intensity and sex on HDL cholesterol changes, as well as the interaction effect between both variables. The study was conducted over eight weeks at the SSI (Senam Sehat Indonesia) PWRI exercise group in Karangpandan District, Karanganyar Regency, Central Java, Indonesia. Ethical clearance was obtained from the Health Research Ethics Committee of Sebelas Maret University (No. 123/UN27.06.6.1/KEPK/EC/2025).

Table 1. 2×2 Factorial Design Structure

	Light Intensity (A1) 40–60% 1RM	Moderate Intensity (A2) 60–75% 1RM	Total per Sex
Male (B1)	A1B1 (n = 8)	A2B1 (n = 8)	n = 16
Female (B2)	A1B2 (n = 8)	A2B2 (n = 8)	n = 16
Total per Intensity	n = 16	n = 16	N = 32

A1 = Light Intensity (40–60% 1RM); A2 = Moderate Intensity (60–75% 1RM); B1 = Male; B2 = Female

As shown in Table 1, the 2×2 factorial structure resulted in four balanced experimental groups with eight participants each, ensuring equal cell sizes across both intensity levels and sex categories. A balanced factorial design is methodologically advantageous because it ensures that the main effects of each independent variable and their interaction can be estimated with equal statistical precision, minimising the risk of confounded variance in the ANOVA model [39]. The quasi-experimental approach was selected over a fully randomised controlled design due to the naturalistic community-based setting of the SSI PWRI group, in which complete randomisation of participants was not logistically feasible while still preserving the integrity of the factorial structure [40].

2.2 Population and Sample

The population consisted of all active members of the SSI PWRI Karangpandan exercise group aged 45–75 years, totalling 72 individuals (22 males, 50 females). A purposive sample of 40 participants (20 males, 20 females) was initially selected based on laboratory cost constraints and the matching procedure requirements. Following ordinal pairing by matching on baseline HDL cholesterol values and stratification by sex, the final analysed sample comprised 32 participants (n = 8 per cell). The inclusion and exclusion criteria are summarised in Table 2.

Table 2. Participant Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Active member of SSI PWRI Karangpandan exercise group	Active cardiovascular disease or recent cardiac event (< 6 months)
Age between 45–75 years	Musculoskeletal injuries or physical disabilities limiting exercise
No diagnosed cardiovascular disease or heart failure	Current use of lipid-lowering or hormone therapy medications
No musculoskeletal disorders precluding resistance training	History of liver or kidney disease affecting lipid metabolism
Not currently using lipid-lowering medications (statins, fibrates)	Participation in structured exercise programme outside of study
Fasting blood glucose < 200 mg/dL (to exclude uncontrolled diabetes)	Incomplete training attendance (< 80% session compliance)
Willing to participate and sign informed consent	Incomplete blood sampling data (pre- or post-test missing)

The criteria presented in Table 2 were designed to ensure that only participants whose HDL cholesterol responses could be attributed specifically to the resistance training intervention were included in the final analysis. Exclusion of individuals with pre-existing cardiovascular conditions, lipid-lowering medication use, or liver and

kidney disease was particularly important given the direct influence of these factors on lipoprotein metabolism and HDL cholesterol levels. The 80% attendance compliance threshold was applied to ensure sufficient training exposure across all participants, as incomplete adherence may substantially attenuate the expected lipid adaptation response.

2.3 Data Sources and Data Collection Techniques

Data collection was conducted through two primary sources: (1) a structured resistance training intervention, and (2) laboratory-based blood examination. The training intervention consisted of eight weeks of supervised resistance training performed three times per week. Each session included a standardised warm-up (10 minutes), resistance exercise block, and cool-down (10 minutes). The light-intensity group performed 35 repetitions per set at 40–60% of their estimated 1-repetition maximum (1RM), while the moderate-intensity group performed 40–45 repetitions per set at 60–75% 1RM. Load progression was implemented weekly by a certified fitness instructor to maintain the prescribed intensity range throughout the intervention.

HDL cholesterol levels were measured at baseline (pre-test) and after the eight-week intervention (post-test). Venous blood samples were obtained from the antecubital vein under fasting conditions of at least 10 hours by certified laboratory personnel. HDL cholesterol analysis was performed using the enzymatic colorimetric method at an accredited clinical laboratory (Laboratorium Klinik Prodia, Surakarta). All participants provided written informed consent prior to participation.

2.4 Research Instruments

Multiple research instruments were employed to measure, monitor, and control the variables investigated in this study. The selection of instruments was based on the conceptual framework of the research, which examined the effects of resistance training intensity and biological sex on changes in high-density lipoprotein cholesterol (HDL-C) levels. The instruments were designed to capture the independent variables, dependent variable, control variables, and baseline participant characteristics to ensure accurate data collection and minimize potential confounding factors. A detailed description of the research instruments, measurement indicators, data collection techniques, and measurement scales is presented in Table 3.

Table 3. Research Instruments

Variable	Indicator	Data Collection Technique	Instrument	Scale
Resistance Training Intensity (Independent Variable)	Training load (% 1RM), repetitions, frequency, duration	Direct observation & training log	Training protocol sheet, 1RM test	Nominal (A1/A2)
Biological Sex (Independent Variable)	Male/ Female classification	Medical records & participant registration	Registration form	Nominal (B1/B2)
HDL Cholesterol Level (Dependent Variable)	Blood HDL-C concentration (mg/dL) pre- and post-intervention	Laboratory blood test (enzymatic colorimetric)	Blood analysis report from accredited laboratory	Ratio (mg/dL)
Physical Health Status (Control Variable)	Absence of musculoskeletal disorders, CVD, lipid-lowering medication	Medical screening & informed consent	Health screening checklist, inclusion/exclusion criteria form	Nominal (Eligible/Not Eligible)
Baseline Characteristics	Age, body weight, baseline HDL, activity level	Anthropometric measurement & questionnaire	Anthropometric assessment sheet	Interval/Ratio

As shown in Table 3, the study utilized different instruments according to the characteristics of each research variable. Resistance training intensity, as the primary independent variable, was assessed through training load expressed as a percentage of one-repetition maximum (1RM), repetitions, sets, frequency, and intervention duration. The training protocol sheet and 1RM testing procedure were used to ensure that participants followed the prescribed training intensity for each experimental group.

Biological sex was included as an additional independent variable and was classified based on participant registration data and medical records. Participants were categorized into male and female groups to examine potential differences in HDL-C responses following the resistance training intervention. The dependent variable, HDL cholesterol level, was objectively measured through laboratory-based blood analysis using an enzymatic colorimetric method. Blood samples were collected before and after the intervention period, and HDL-C concentrations were reported in milligrams per deciliter (mg/dL).

Physical health status was assessed as a control variable to ensure participant eligibility and reduce the influence of external health-related factors. Medical screening procedures were conducted to identify the presence of cardiovascular disease, musculoskeletal disorders, or the use of lipid-lowering medications. Participants who met the inclusion criteria were considered eligible for participation in the intervention.

In addition, baseline characteristics, including age, body weight, baseline HDL-C level, and physical activity level, were collected to describe participant profiles and support the interpretation of study findings. Anthropometric measurements and questionnaires were administered using standardized assessment sheets. Collectively, these instruments provided comprehensive measurements of the study variables and supported the internal validity of the experimental design.

2.5 Training Protocol

The resistance training protocol for both groups was standardised in terms of exercise selection, session structure, and frequency, differing only in intensity level (% 1RM) and target repetitions per set. The complete protocol specifications are presented in Table 4.

Table 4. Resistance Training Protocol by Intensity Group

Parameter	Light Intensity (A1)	Moderate Intensity (A2)	Notes
Intensity Level	Light Intensity (A1)	Moderate Intensity (A2)	
% 1RM	40–60% 1RM	60–75% 1RM	
Sets per Exercise	3 sets	3 sets	
Repetitions per Set	35 repetitions	40–45 repetitions	
Rest Between Sets	60–90 seconds	90–120 seconds	
Session Duration	45–60 minutes	50–65 minutes	
Frequency	3 sessions/week	3 sessions/week	
Intervention Duration	8 weeks	8 weeks	
Exercises Included	Squats, bicep curls, shoulder press, leg press, seated row, triceps extension	Same exercises as A1, with increased load	
Warm-Up	10 minutes (light aerobic + dynamic stretching)	10 minutes (light aerobic + dynamic stretching)	Both groups
Cool-Down	10 minutes (static stretching)	10 minutes (static stretching)	Both groups
Progression	Load adjusted weekly to maintain 40–60% 1RM	Load adjusted weekly to maintain 60–75% 1RM	

1RM = One Repetition Maximum; Sessions conducted under supervision of a certified resistance training instructor

As presented in Table 4, the resistance training protocol was standardized across both intervention groups, with the main distinction being the prescribed intensity level and corresponding repetition range. The light-intensity group (A1) performed resistance exercises at 40–60% of one-repetition maximum (1RM), whereas the moderate-intensity group (A2) trained at 60–75% of 1RM. This approach allowed the study to examine the effects of different resistance training intensities while minimizing potential confounding effects arising from variations in exercise type, training volume structure, or session frequency.

Both groups completed three training sessions per week over an 8-week intervention period. Each session consisted of the same resistance exercises targeting major muscle groups, including squats, biceps curls, shoulder presses, leg presses, seated rows, and triceps extensions. The number of sets was maintained at three sets per exercise for both groups, while repetition targets were adjusted according to the assigned intensity condition. The moderate-intensity group received a higher external load with fewer repetitions relative to the light-intensity group, reflecting the physiological differences associated with resistance training intensity manipulation.

To maintain progressive overload and ensure that the intended training intensity was preserved throughout the intervention, training loads were reassessed and adjusted weekly based on participants' performance and the targeted percentage of 1RM. All training sessions were conducted under the supervision of a certified resistance training instructor to ensure proper exercise technique, adherence to the prescribed protocol, and participant safety.

The training sessions lasted approximately 45–60 minutes for the light-intensity group and 50–65 minutes for the moderate-intensity group. Each session began with a 10-minute warm-up consisting of light aerobic activity and dynamic stretching, followed by the resistance training protocol, and concluded with a 10-minute cool-down involving static stretching. These standardized procedures were implemented to reduce injury risk and maintain consistency in physiological preparation and recovery across both groups.

2.6 Data Analysis Techniques

Data were analysed using descriptive and inferential statistical techniques performed with IBM SPSS Statistics Version 26.0. Descriptive statistics were used to summarize baseline and post-intervention HDL cholesterol values, as well as changes in HDL cholesterol (Δ HDL), presented as mean $\pm$ standard deviation (M $\pm$

SD). Prior to hypothesis testing, the assumptions of normality and homogeneity of variance were examined using the Lilliefors normality test and Bartlett's test, respectively. All assumptions were evaluated at a significance level of $\alpha = 0.05$.

A two-way analysis of variance (2×2 factorial ANOVA) was subsequently conducted to examine the main effects of resistance training intensity (A), biological sex (B), and the interaction effect between intensity and sex ($A \times B$) on Δ HDL. Statistical significance was determined at $\alpha = 0.05$. The magnitude of observed effects was assessed using eta squared (η^2), calculated using the following formula:

$$\eta^2 = \frac{SS_{effect}}{SS_{total}} \quad (1)$$

Effect sizes were interpreted based on conventional thresholds, with η^2 values of approximately 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively.

2.7 Research Procedure

The research procedure consisted of five sequential stages: participant recruitment and screening, baseline assessment, group allocation, resistance training intervention, and post-intervention evaluation. Participants were recruited from the SSI (Senam Sehat Indonesia) PWRI exercise group in Karangpandan District, Karanganyar Regency, Central Java, Indonesia. Screening was conducted based on predefined inclusion and exclusion criteria, including age eligibility, cardiovascular health status, medication history, and readiness to engage in resistance training. Eligible participants provided written informed consent prior to participation.

Baseline assessments included anthropometric measurements and fasting high-density lipoprotein (HDL) cholesterol analysis. Participants were stratified by biological sex and allocated into resistance training intensity groups using an ordinal matching procedure based on baseline HDL cholesterol levels to ensure comparability between groups. The intervention was conducted over eight weeks, with supervised resistance training performed three times per week. The light-intensity group trained at 40–60% of one-repetition maximum (1RM), while the moderate-intensity group trained at 60–75% of 1RM. Training attendance, compliance, and load progression were continuously monitored by a certified resistance training instructor.

Post-intervention HDL cholesterol levels were measured using the same laboratory procedures as the baseline assessment. All data were subsequently analyzed to examine the main effects of resistance training intensity, biological sex, and their interaction on HDL cholesterol changes. The overall procedure is summarized in Figure 1.

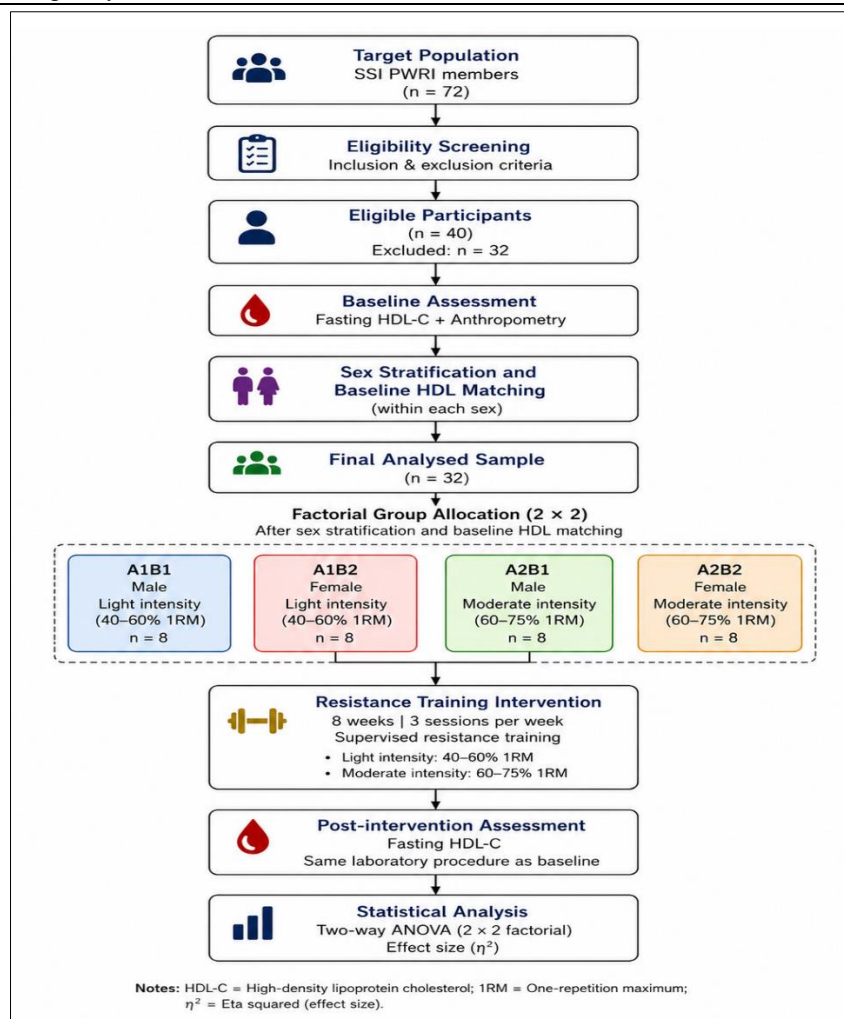


Figure 1. Research Flow Diagram

Figure 1 illustrates the overall flow of the experimental procedure, from participant recruitment to statistical analysis. Following eligibility screening and baseline assessment, participants were stratified by biological sex and matched according to baseline HDL cholesterol levels before being allocated into the 2×2 factorial intervention groups. This procedure ensured comparable baseline characteristics across groups prior to the 8-week resistance training intervention. The post-intervention HDL cholesterol changes were subsequently analyzed using two-way ANOVA to determine the main effects of training intensity, biological sex, and their interaction.

3. RESULTS AND DISCUSSION

3.1 Baseline Characteristics and Descriptive Statistics

Baseline and post-intervention HDL cholesterol values across all four experimental groups are presented in Table 5. All groups demonstrated positive changes in HDL cholesterol following the 8-week resistance training intervention, suggesting an overall favourable change in lipid profile across both sexes and training intensity levels. Notably, female subgroups consistently exhibited greater absolute increases in HDL cholesterol compared with their male counterparts.

Table 5. Descriptive Statistics of HDL Cholesterol by Intervention Group

Group	Intensity × Sex	n	HDL Pre (mg/dL) M ± SD	HDL Post (mg/dL) M ± SD	ΔHDL M ± SD
A1B1	Light × Male	8	38.31 ± 11.38	47.19 ± 14.88	+8.88
A1B2	Light × Female	8	44.19 ± 5.87	61.13 ± 12.10	+16.94
A2B1	Moderate × Male	8	38.31 ± 11.38	48.81 ± 14.88	+10.50
A2B2	Moderate × Female	8	44.06 ± 7.76	57.06 ± 13.09	+13.00

ΔHDL = Post minus Pre HDL cholesterol; M = Mean; SD = Standard Deviation

Table 5 demonstrates two descriptive patterns. First, baseline HDL cholesterol concentrations were higher in female groups (A1B2: 44.19 mg/dL; A2B2: 44.06 mg/dL) compared with male groups (A1B1 and A2B1: 38.31 mg/dL). This pattern is consistent with previously reported sex-related differences in lipid metabolism, although these differences may also be influenced by age, hormonal status, and body composition [41]. Second, among male participants, the moderate-intensity group demonstrated a slightly greater mean increase in HDL cholesterol (A2B1: +10.50 mg/dL) compared with the light-intensity group (A1B1: +8.88 mg/dL). However, this descriptive difference required inferential testing to determine statistical significance, as presented in Section 3.3.

Table 6. Marginal Means of HDL Cholesterol Change (Δ HDL) by Training Intensity and Biological Sex

Factor	Category	n	Mean Δ HDL (mg/dL)
Training Intensity	Light (A1)	16	12.91
	Moderate (A2)	16	11.75
Biological Sex	Male (B1)	16	9.69
	Female (B2)	16	14.97

Note: Δ HDL = change in HDL cholesterol calculated as post-intervention HDL cholesterol minus baseline HDL cholesterol.

The marginal means presented in Table 6 provide a descriptive overview of HDL cholesterol changes according to training intensity and biological sex prior to inferential analysis. Regarding training intensity, the mean Δ HDL values were comparable between the light-intensity group (12.91 mg/dL) and moderate-intensity group (11.75 mg/dL), indicating similar HDL responses across the two resistance training conditions. This pattern suggests that, within the intensity range examined in this study, increasing resistance training intensity from light to moderate levels did not substantially alter HDL cholesterol improvement. This finding is consistent with previous evidence indicating that resistance training performed at lower intensities may still produce favourable lipid adaptations among older and relatively deconditioned populations [31].

In contrast, biological sex showed a more pronounced descriptive difference in HDL response. Female participants demonstrated a higher mean Δ HDL (14.97 mg/dL) compared with male participants (9.69 mg/dL), indicating greater average HDL improvement among female participants following the intervention. This observation aligns with previous evidence reporting sex-related differences in exercise-induced lipid responses among middle-aged and older adults [42].

These descriptive patterns provide an initial indication of potential differences across experimental factors; however, statistical significance and effect magnitude were subsequently evaluated using two-way ANOVA.

3.2 Normality and Homogeneity Testing

The Lilliefors normality test confirmed that the data were normally distributed across all four experimental cells: A1B1 ($L = 0.222$; $L_{critical} = 0.313$), A1B2 ($L = 0.189$; $L_{critical} = 0.313$), A2B1 ($L = 0.218$; $L_{critical} = 0.313$), and A2B2 ($L = 0.107$; $L_{critical} = 0.313$). Bartlett's test further indicated homogeneity of variance across groups ($\chi^2 = 8.06 < \chi^2_{critical} = 11.1$, $p > 0.05$), at a significance level of $\alpha = 0.05$. These results confirm that the assumptions for parametric two-way ANOVA were satisfied for all analyses.

3.3 Two-Way ANOVA Results

To examine the effects of resistance training intensity and biological sex on changes in high-density lipoprotein (HDL) cholesterol, a two-way analysis of variance (2×2 factorial ANOVA) was conducted. This analysis evaluated the main effects of training intensity (light vs. moderate), biological sex (male vs. female), and their interaction on HDL cholesterol changes (Δ HDL) following the 8-week intervention. The results are presented in Table 7.

Tabel 7 (sinkron dengan Tabel 5/6)

Source of Variance	df	SS	MS	F-value	p-value	η^2	Interpretation
Training Intensity (A)	1	10.76	10.76	0.09	0.769	0.003	Negligible
Biological Sex (B)	1	223.03	223.03	1.83	0.187	0.060	Medium (n.s.)
Intensity $\times$ Sex (A $\times$ B)	1	61.83	61.83	0.51	0.482	0.017	Small
Error	28	3415.38	121.98	—	—	—	—
Total	31	3711.00	—	—	—	—	—

The two-way ANOVA revealed that training intensity did not significantly affect HDL cholesterol changes ($F(1,28) = 0.09$, $p = 0.769$, $\eta^2 = 0.003$), indicating a negligible effect of intensity on HDL improvement.

Biological sex did not reach a statistically significant main effect on Δ HDL ($F(1,28) = 1.83$, $p = 0.187$, $\eta^2 = 0.060$). Although female participants showed a higher average HDL increase than male participants at the descriptive level, this difference was not statistically significant. Notably, the effect size was medium, suggesting that a true sex-based difference may exist but that the present study was likely underpowered ($N = 32$) to detect it.

The interaction between training intensity and biological sex was not statistically significant ($F(1,28) = 0.51$, $p = 0.482$, $\eta^2 = 0.017$), indicating that the influence of training intensity on HDL adaptation was comparable between male and female participants.

3.4 Equivalent HDL Elevation at Light and Moderate Resistance Training Intensity

The present study found that light and moderate intensity resistance training produced comparable increases in HDL cholesterol over the 8-week intervention period (Δ HDL: 12.91 vs. 11.75 mg/dL). This finding is consistent with the ANOVA results, which indicated no statistically significant main effect of training intensity on HDL change, accompanied by a negligible effect size ($\eta^2 = 0.0003$). From a practical perspective, these results suggest that within the intensity range examined (40–75% 1RM), resistance training intensity may not be a primary determinant of HDL response in middle-aged and older adults. Instead, the overall training exposure, including frequency, duration, and cumulative workload, may play a more important role in influencing lipid adaptations.

This pattern may be explained by the possibility that both training conditions provided sufficient physiological stimulus to activate lipid metabolism pathways associated with HDL regulation. In older adult populations, even relatively moderate mechanical and metabolic stress may be adequate to induce favorable changes in lipid transport and utilization, reducing the likelihood of large differences between adjacent intensity domains. It is important to interpret these findings within the context of the study design. Since both groups performed structured and supervised resistance training with similar exercise volume and duration, the absence of a significant intensity effect may reflect a convergence of total training stimulus rather than a lack of physiological response to intensity per se. The findings indicate that both light and moderate resistance training can be considered effective and comparable strategies for improving HDL cholesterol in older adults, which may have practical implications for exercise prescription in populations with varying functional capacity.

3.5 Sex-Related Trend in HDL Response: Effect Size, Statistical Power, and Mechanisms

At the descriptive level, female participants showed a higher mean HDL increase than male participants (14.97 vs. 9.69 mg/dL), a difference of approximately 1.5-fold. However, the two-way ANOVA indicated that this sex difference did not reach statistical significance ($F(1,28) = 1.83$, $p = 0.187$), although the associated effect size was medium ($\eta^2 = 0.060$). This combination of a non-significant p -value with a non-trivial effect size warrants careful interpretation rather than a simple null conclusion.

A key explanation lies in statistical power. A post-hoc power analysis indicated that, given the observed effect size ($\eta^2 = 0.060$) and the sample size ($N = 32$), the achieved power to detect a sex main effect was only approximately 0.28, far below the conventional 0.80 threshold. Detecting an effect of this magnitude with adequate power would require a sample of roughly 126 participants. The substantial within-group variability evident in Table 5 (standard deviations of 12–15 mg/dL) further reduced the precision of the between-sex comparison. Taken together, these factors suggest that a genuine sex-related difference may well exist, but that the present study was underpowered to detect it. The medium effect size is therefore arguably more informative than the non-significant p -value and provides a useful basis for sample-size planning in future trials.

The direction of the observed trend is consistent with existing evidence regarding sex-related differences in lipoprotein metabolism. Masuda et al. [41] demonstrated sex-stratified differences in plasma lipoprotein profiles among middle-aged and older adults, while Vladimirov et al. [42] reported distinct cholesterol-metabolism patterns between men and women. In the exercise domain, Pourmontaseri et al. [26] showed favourable lipid responses following aerobic and resistance training in women. Although our female participants demonstrated a higher descriptive Δ HDL (+14.97 mg/dL) compared with males (+9.69 mg/dL), the between-sex difference did not reach statistical significance, likely reflecting limited statistical power rather than the absence of a potential sex-related response pattern.

Several mechanisms could plausibly underlie a greater female HDL responsiveness, although they must be interpreted cautiously in this population. Sex hormones, particularly oestrogen, modulate hepatic lipase activity and apolipoprotein A-I production, both central to HDL metabolism. Importantly, however, the female participants in this study were aged 45–75 years and therefore largely postmenopausal, a state characterised by declining oestrogen. Oestrogen-dependent mechanisms are thus unlikely to fully account for the observed trend, and menopausal status was not assessed in the present study a limitation that tempers any hormonal interpretation. Non-hormonal factors may be more relevant: at a comparable absolute external load, female participants who typically have lower baseline strength and muscle mass may experience a higher relative training stimulus, potentially producing greater metabolic stress and lipid adaptation. Differences in baseline body composition may further contribute.

Finally, the interaction between sex and training intensity was not significant ($F(1,28) = 0.51$, $p = 0.482$, $\eta^2 = 0.017$), indicating that the descriptive sex-related trend was broadly consistent across both light and moderate intensities. Overall, these findings should be read as a hypothesis-generating signal: they support the inclusion of sex as a stratification variable in future, adequately powered resistance-training trials, while stopping short of establishing a confirmed sex difference in HDL adaptation.

3.6 Cardiovascular Risk Implications for Older Adult Populations

The increases in HDL cholesterol observed in this study across both training intensities and biological sexes may have important implications for cardiovascular health in older adult populations. Although HDL cholesterol is not a direct causal determinant of cardiovascular disease outcomes, it is widely recognized as a key component of the overall lipid profile associated with cardiometabolic risk. The magnitude of HDL improvement observed in this study (approximately 11.75–14.97 mg/dL, depending on group allocation) suggests a favorable shift in lipid metabolism following resistance training. While epidemiological evidence has previously linked higher HDL levels with lower cardiovascular risk, such associations should be interpreted cautiously in the absence of direct clinical outcome measurements.

From a practical perspective, the present findings highlight the potential value of community-based resistance training programs for older adults. The SSI PWRI setting represents a real-world, group-based exercise environment that may enhance accessibility and adherence among aging populations [43]. Such community-based models are particularly relevant in contexts where access to structured clinical exercise facilities is limited. Importantly, the absence of a significant difference between light- and moderate-intensity training suggests that lower-intensity resistance exercise may provide a viable and inclusive option for older adults with varying functional capacities. This may be particularly relevant for individuals who are less physically conditioned or who perceive higher-intensity exercise as less feasible. These findings support the potential role of structured resistance training as part of broader lifestyle-based strategies for improving lipid profiles in older adult populations, while recognizing that direct cardiovascular risk reduction cannot be inferred from HDL changes alone.

3.7 Limitations and Future Research Directions

Several limitations of this study should be acknowledged. First, the relatively small sample size ($N = 32$) limited statistical power and reduced the generalisability of the findings, particularly for the between-sex comparison. A post-hoc analysis indicated that the achieved power to detect the observed sex effect was only approximately 0.28, well below the conventional 0.80 threshold; consequently, the non-significant sex difference should be interpreted as an underpowered result rather than evidence of no effect.

Second, the study was conducted within a single community-based setting (SSI PWRI, Karangpandan), which may limit the transferability of the findings to other populations with different demographic characteristics, health statuses, or exercise habits. Contextual factors such as cultural attitudes toward physical activity and baseline fitness levels may also influence responsiveness to resistance training. Third, dietary intake was not strictly controlled during the intervention period. Since nutritional factors, particularly fat and cholesterol intake, can independently influence lipid metabolism, this may have introduced uncontrolled variability in HDL outcomes.

Fourth, the relatively short intervention duration (8 weeks) captures only short-term physiological adaptations and does not allow for assessment of the long-term maintenance of HDL improvements or sustained training effects. Fifth, the quasi-experimental design did not include a non-exercising control group. The absence of a true control condition limits causal inference and means that the observed HDL changes cannot be fully disentangled from time-related or seasonal influences on lipid metabolism. Sixth, the menopausal and hormonal status of the female participants was not assessed. Given that participants were aged 45–75 years and therefore largely postmenopausal, this omission constrains the interpretation of the estrogen-related mechanisms discussed in Section 3.5 and should be addressed directly in future work.

Future research should consider more rigorous experimental designs, including randomized controlled trials where feasible, to strengthen causal inference. Crucially, studies should be adequately powered; on the basis of the present effect-size estimates, a sample of roughly 126 participants would be required to detect a sex effect of this magnitude with 80% power. Incorporating a non-exercising comparison group, monitoring dietary intake, and recording menopausal status would further help isolate the specific effects of resistance training on lipid profiles.

Further investigations may also extend the intervention period and examine multiple levels of training intensity, including higher intensities, to better characterize potential dose–response relationships. The inclusion of additional lipid-related biomarkers, such as LDL cholesterol, triglycerides, apolipoprotein A-I, and apolipoprotein B, would provide a more comprehensive assessment of lipoprotein metabolism responses. Finally, longitudinal studies are needed to determine whether the observed improvements in HDL cholesterol are maintained over time and whether sex-based differences persist with prolonged training exposure.

3.8 Cross-National Comparative Context: Indonesia, Egypt, and Mexico

The present study was conducted in Central Java, Indonesia, where cardiovascular disease remains the leading cause of mortality [44], [45]. National Basic Health Research indicate a hypercholesterolemia prevalence of approximately 38.2% among Indonesians aged 65–74 years, with a low-HDL phenotype identified as a sex-differentiated risk factor: low HDL was more prevalent in men, whereas elevated total cholesterol and LDL were more prevalent in women [46], [47]. A subsequent multi-centre registry study (2022–2023) across eight Indonesian

provinces documented persistent gaps in dyslipidaemia management among high-risk patients, underscoring the inadequacy of pharmacological strategies alone and the urgency of scalable non-pharmacological interventions. The SSI PWRI community exercise model employed in the present study directly addresses this gap, demonstrating that structured group-based resistance training is both feasible and clinically effective within the Indonesian community health infrastructure [48], [49]. The finding that light-intensity training produces HDL gains equivalent to moderate-intensity training is particularly relevant to the Indonesian context, where older adults frequently present with musculoskeletal limitations, lower exercise capacity, and limited access to supervised fitness facilities.

Egypt faces a disproportionately high burden of premature atherosclerotic cardiovascular disease, with the Egyptian CardioRisk project (2020) reporting that 51% of Egyptians experience premature acute coronary syndrome, and dyslipidemia is identified as a modifiable risk factor in 48.2% of the population [50]. A long-term trend analysis across the Middle East and North Africa (MENA) region further documented that women carry a higher dyslipidemia burden than men (pooled proportion: 72% vs. 65%), a pattern consistent with the female-dominant HDL deficits observed in aging Egyptian cohorts [51], [52]. The 2025 Egyptian National Dyslipidemia Guidelines explicitly acknowledged the insufficiency of pharmacological management alone and called for context-adapted lifestyle strategies, including structured physical activity, as first-line interventions [53], [54]. The descriptive trend toward greater HDL elevation in female participants in the present study (marginal means 14.97 vs. 9.69 mg/dL; a non-significant difference, see Section 3.5) may nonetheless be of potential relevance to the Egyptian healthcare context, where postmenopausal women represent a high-priority target group for HDL-raising non-pharmacological interventions [55], [56]. Community-based resistance training programs analogous to the SSI PWRI model could offer a cost-effective, scalable solution for the Egyptian public health system, which currently faces resource constraints that limit widespread pharmacotherapy coverage [57], [58].

Mexico presents a closely comparable epidemiological profile. The National Health and Nutrition Survey (ENSANUT) reported that 58.9% of Mexican adults exhibit HDL-cholesterol levels below 40 mg/dL, qualifying as hypoalphalipoproteinaemia, with older women disproportionately affected [59], [60]. A 2025 study analyzing ENSANUT data from 2016–2023 demonstrated that cardiovascular risk continued to rise despite improvements in LDL-C pharmacological control, highlighting the critical role of HDL-raising strategies as a complementary therapeutic target [61]. Analyses of gender differences in Mexican CVD risk factors further confirmed that dyslipidemia, obesity, and hypertension in women were independently associated with a 2.6-fold increased odds of CVD diagnosis, reinforcing the clinical importance of sex-stratified intervention design. The Universidad Autónoma de Chihuahua's collaboration in this study reflects the broader Mexican public health interest in developing exercise-based cardiovascular rehabilitation strategies that are adapted to the physical capacities and sociocultural preferences of older Latin American adults [62]. The present study's demonstration that both light and moderate resistance training intensities achieve equivalent HDL gains provides empirically grounded guidance for the design of inclusive exercise programs for Mexico's aging population, particularly in rural and peri-urban settings where high-intensity gym-based training is logistically inaccessible [63], [64].

Despite increasing evidence regarding exercise-based cardiovascular prevention, previous studies in Indonesia, Egypt, and Mexico have largely focused on disease prevalence, pharmacological management, or observational assessment of cardiovascular risk factors. Limited evidence is available regarding whether resistance training intensity produces comparable HDL adaptations across sexes within ageing community populations. Furthermore, cross-national comparisons integrating biological sex, exercise intensity, and community-based implementation remain scarce. Therefore, the present study provides a novel contribution by examining intensity-specific and sex-related HDL responses through a controlled resistance training intervention and discussing its applicability across different socioeconomic and healthcare contexts.

Taken together, the convergent cardiovascular disease burden and dyslipidemia profiles of Indonesia, Egypt, and Mexico underscore the cross-national relevance of this study's findings. All three countries are confronted with aging populations, high rates of low HDL, female-predominant lipid vulnerability, and limited capacity to scale pharmacological interventions. The evidence presented here that community-based resistance training at either light or moderate intensity reliably elevates HDL cholesterol across both sexes, with a descriptive (non-significant) trend toward greater gains in women constitutes a transferable low-cost public health strategy that aligns directly with the unmet cardiovascular prevention needs of these health systems.

However, several limitations should be considered when interpreting the cross-national implications of these findings. First, the present study was conducted in a specific Indonesian community setting, and direct generalisation to Egypt, Mexico, or other populations should be made cautiously due to differences in healthcare systems, lifestyle behaviours, genetic backgrounds, and exercise participation patterns. Second, although the comparative discussion highlights potential transferability, the study did not directly evaluate intervention outcomes across multiple countries. Future multinational trials are therefore required to confirm whether similar resistance training responses can be consistently achieved across diverse ageing populations.

4. CONCLUSION

This factorial experimental study demonstrates that both light- and moderate-intensity resistance training effectively increase HDL cholesterol levels in older adults after an 8-week intervention, with no significant differences between training intensities. These findings indicate that light-intensity resistance training may represent a practical and accessible cardiovascular health strategy for ageing populations, particularly those with limited exercise capacity or musculoskeletal constraints. Although female participants showed a descriptive trend toward greater HDL improvement than males, the difference was not statistically significant. However, the observed medium effect size suggests that potential sex-related differences in lipid adaptation warrant further investigation through larger and adequately powered studies. Therefore, biological sex should be considered as an important stratification factor in future resistance training research rather than as a determinant for different clinical recommendations at the current stage.

The findings support the implementation of community-based resistance training programmes as a low-cost and scalable approach for cardiovascular risk reduction among older adults. Healthcare providers and community exercise programmes should consider incorporating structured resistance training at tolerable intensities to improve lipid profiles and promote healthy ageing. Future research should employ larger samples, longer intervention periods, dietary control, non-exercise comparison groups, and direct cardiovascular outcomes to confirm long-term effectiveness and clarify sex-specific responses.

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AUTHOR CONTRIBUTIONS

Conceptualization, I.S.E. and A.Y.; Methodology, I.S.E. and A.Y.; Validation, A.Y. and C.M.S.A.; Formal Analysis, I.S.E.; Investigation, I.S.E.; Resources, I.S.E., A.Y., and C.M.S.A.; Data Curation, I.S.E.; Writing – Original Draft Preparation, I.S.E.; Writing – Review & Editing, A.Y. and C.M.S.A.; Visualization, I.S.E.; Supervision, A.Y. and C.M.S.A.; Project Administration, I.S.E.; All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest associated with this study, including any financial, personal, or institutional relationships that could have influenced the research design, data collection, analysis, interpretation of results, or preparation of the manuscript.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

AI-assisted tools were used solely for language editing and improvement of manuscript readability. The authors remain fully responsible for the accuracy, originality, and integrity of the content presented in this manuscript.

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