

Original article

Association between adherence to a 12-week multicomponent exercise program and changes in high-density lipoprotein cholesterol in community-dwelling older adults

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Abstract

Background and Purpose: Attendance at supervised sessions alone may not fully reflect adherence to home-based exercise. This study examined the association between multicomponent exercise adherence quantified from an 84-day diary and changes in high-density lipoprotein cholesterol (HDL-C). **Methods:** Seventy-five community-dwelling older adults (mean age 73.2 ± 6.7 years; 50 women) completed a 12-week program comprising weekly supervised exercise plus home-based step exercise, resistance exercise, and stretching. Participants were asked to maintain usual dietary habits. A composite adherence score was created from standardized exposure to the three exercise components. Participants were classified as Low (0 criteria, $n = 15$), Intermediate (1–2 criteria, $n = 32$), or High (3 criteria, $n = 28$). Regression analyses adjusted for age, sex, and baseline HDL-C. **Results:** HDL-C increased from 70.2 ± 17.0 to 74.3 ± 18.6 mg/dL (mean change $+4.1 \pm 8.0$ mg/dL, $p < 0.001$). Mean changes were -2.5 , $+5.1$, and $+6.6$ mg/dL in the Low, Intermediate, and High groups (unadjusted between-group $p < 0.001$). Each 1-SD increase in the composite score was associated with a 5.23-percentage-point greater percentage change in HDL-C (95% CI 2.70–7.76, $p < 0.001$). Adjusted changes were greater in the Intermediate and High groups than in the Low group; High and Intermediate did not differ ($p = 0.193$). **Conclusion:** Greater adherence across multiple exercise components was associated with larger HDL-C increases, but causality cannot be established without a non-exercise control group.

Keywords: HDL cholesterol, exercise adherence, resistance training, exercise diary

Introduction

In aging societies, maintaining physical function while preventing cardiometabolic disease is important for prolonging independent living. The World Health Organization (WHO) and expert recommendations for exercise in older adults advocate the regular inclusion of multiple exercise components, including aerobic physical activity, muscle-strengthening exercise, and balance training (World Health Organization, 2020; Izquierdo et al., 2021). The Japanese Physical Activity Guide for Health Promotion 2023 likewise recommends that older adults perform at least 40 min/day of walking or equivalent physical activity (approximately 6,000 steps/day), multicomponent exercise at least 3 days/week, and resistance exercise 2–3 days/week (Ministry of Health, Labour and Welfare, 2024). Recent systematic reviews and meta-analyses indicate that multicomponent exercise can improve strength, walking ability, balance, and functional fitness in community-dwelling and frail older adults (Labata-Lezaun et al., 2023; Li et al., 2023; Alowaydhah et al., 2024; Toosi et al., 2026). Exercise training may also influence cardiometabolic markers, including serum lipids (Yun et al., 2023; Smart et al., 2025; Hejazi et al., 2025).

Among serum lipids, high-density lipoprotein cholesterol (HDL-C) is a commonly assessed marker that may change with physical activity and habitual exercise. HDL participates in reverse cholesterol transport and has several potentially protective functions, including antioxidant and anti-inflammatory actions; exercise may influence not only HDL quantity but also HDL function (Ruiz-Ramie et al., 2019; Franczyk et al., 2023). Moreover, a systematic review and meta-analysis has shown that greater cholesterol efflux capacity and antioxidant and anti-inflammatory HDL functions are associated with lower risks of cardiovascular disease and mortality, suggesting that HDL function, in addition to HDL-C concentration, is clinically relevant (Soria-Florido et al., 2020).

Regarding exercise and HDL-C, a recent large meta-analysis showed that exercise training, including aerobic exercise, resistance training, and combined modalities, increased HDL-C by approximately 2 mg/dL on average (Smart et al., 2025). A meta-analysis focused on older adults also reported significant increases in HDL-C with aerobic exercise (Yun et al., 2023), and a recent meta-analysis in middle-aged and older individuals further supports beneficial effects of regular exercise on HDL-C (Liang et al., 2025). In East Asian populations, the HDL-C response may vary according to exercise volume and intensity (Igarashi et al., 2019). Conversely, lipid responses to resistance training alone or in combination with aerobic exercise are not uniform across populations or exercise prescriptions (Yun et al., 2023; Hejazi et al., 2025; Smart et al., 2025). Therefore, in multicomponent exercise programs, it is important to consider not only the prescribed program but also how consistently participants actually perform each exercise component. However, the relationship between actual adherence to individual components of a multicomponent exercise program and the HDL-C response remains insufficiently characterized in community-dwelling older adults.

Many older adults who participate in community health-promotion programs already have exercise habits, such as regular walking, before entering a study. In such populations, an important practical question is not simply how to increase walking volume but how to add and sustain different exercise components, such as resistance and flexibility exercise, alongside existing physical activity. In exercise interventions for older adults, attendance, completion rates, and home-exercise performance are commonly used as adherence indicators, and support strategies including feedback and monitoring have been associated with better adherence (Room et al., 2017). Home-based programs for older adults have also achieved high adherence through self-monitoring and regular support (Rihova et al., 2024; dos Santos et al., 2024). Nevertheless, in programs combining supervised group exercise with home exercise, attendance or total exercise frequency alone may not adequately capture how much of each exercise component is actually performed. Quantifying each component separately and integrating these measures into an overall adherence indicator may therefore provide additional information.

Accordingly, this study examined community-dwelling older adults who participated in a 12-week multicomponent exercise program consisting of weekly supervised group exercise plus home-based step exercise, resistance exercise, and stretching. Exercise exposure for each component was quantified from an 84-day exercise diary, and the association between multicomponent exercise adherence and changes in HDL-C was evaluated. The primary analysis used a continuous composite adherence score, together with an exploratory comparison across Low, Intermediate, and High adherence groups. The primary hypothesis was that participants who sustained multiple exercise components at higher levels would exhibit a greater HDL-C response.

Methods

Study design

A prospective single-arm design was used to examine a 12-week community-based multicomponent exercise intervention in older adults living independently. This report represents a distinct analysis within a broader community intervention project and focuses specifically on diary-derived exercise adherence and HDL-C responses. The broader project collected additional outcomes, but those outcomes are outside the scope of the present report. Measurements relevant to the present analysis were obtained immediately before the intervention (Pre) and again after 12 weeks (Post). The analytic sample comprised 75 participants who had complete Pre/Post HDL-C values together with complete 84-day records for step exercise, resistance exercise, and stretching.

Participants

Recruitment was conducted in Wakayama City and neighboring communities from June through August 2025. Community-dwelling adults 60–85 years of age were eligible if they agreed in writing to the study procedures and assessments and if a physician identified no medical reason that would preclude exercise participation. Analyses of HDL-C were restricted to participants with paired Pre/Post values, whereas other blood outcomes were evaluated using the paired observations available for each marker. Descriptive baseline variables were age, sex, height, body weight, body mass index (BMI), and waist circumference; BMI was computed as body weight (kg)/height (m²). Ethical approval was granted by the Wakayama University Ethics Committee (No. R07-02-01; April 15, 2025). Before enrollment, participants were informed about the aims and procedures, foreseeable benefits and risks, protection of personal information, voluntary participation, and their right to discontinue without penalty, after which written informed consent was obtained. All study procedures conformed to the principles of the Declaration of Helsinki.

Multicomponent exercise program

The intervention followed the Wakayama Senior Exercise framework used in community settings. Participants attended one supervised group session approximately every week for 12 weeks; each session lasted about 90 min. The session sequence included roughly 10 min each of warm-up and stretching, about 20 min of resistance exercise, 10–20 min of stepping, about 20 min of low-intensity recreational activity, and a final 10-min cool-down. Resistance work emphasized body-weight lower-extremity movements: squats, heel raises, hip abduction, leg curls, standing knee raises, thigh raises, and leg raises. Intensity was individualized according to symptoms and functional capacity, with a target rating of perceived exertion (RPE) of 11–13 on the Borg 6–20 scale; the use of RPE for monitoring exercise intensity in older adults is supported by recent studies (Stuckenschneider et al., 2020; Marçal et al., 2022). Stepping was performed for 10–20 min on a 10–20-cm platform in time with music at approximately 60 beats/min. Between supervised sessions, participants were encouraged to reproduce the step, resistance, and stretching activities at home at a safe level, using the class content as a reference. They were also asked to keep their usual diet as stable as possible and not to deliberately change food type or intake during the 12-week period.

Exercise diary and quantification of adherence

A self-completed diary was maintained throughout all 84 intervention days. For each day, participants documented whether they had performed step exercise, resistance exercise, and stretching. Step-exercise exposure was converted to minutes and averaged as weekly minutes. Resistance exercise was coded 1 for completed, 0.5 for partially completed, and 0 for not completed, then summarized as equivalent days per week; stretching was quantified using the same daily scoring approach. Attendance was calculated as the proportion of scheduled supervised sessions actually attended. Mean daily step count during the intervention was also summarized, but step count was not included in the adherence composite. To construct the primary adherence measure, weekly step minutes, resistance-exercise frequency, and stretching frequency were each transformed to z scores and the three standardized values were averaged. This composite was then rescaled to study-sample SD units for regression, allowing coefficients to be interpreted as the difference in HDL-C percentage change associated with a 1-SD higher adherence score. For secondary categorical analyses, participants were classified according to three study-defined exposure criteria: step exercise ≥ 60 min/week, resistance exercise ≥ 5 equivalent days/week, and stretching ≥ 5 equivalent days/week. Meeting no criterion defined the Low group ($n = 15$), meeting one or two defined the Intermediate group ($n = 32$), and meeting all three defined the High group ($n = 28$). These cut points were created only to describe exposure within this sample and are not intended as exercise recommendations. Group assignment used diary information alone, without reference to HDL-C results. The count of criteria met (0–3) was additionally treated as an ordinal exposure variable.

Questionnaire-based physical activity and exercise habits

At both assessment points, a self-administered questionnaire captured the previous week's frequency and duration of walking, other moderate-intensity activity, vigorous-intensity activity, resistance exercise, and stretching. Minutes of walking, moderate-intensity activity, and vigorous-intensity activity were added to provide an aerobic-related physical-activity estimate (min/week), which served as a complementary behavioral measure alongside the diary-derived exercise variables.

Blood tests

Venous blood sampling was completed at both Pre and Post, generally between 9:00 and 10:00 a.m. after an overnight fast. All specimens were analyzed at the Wakayama City Medical Association Seijinbyo Center using the center's routine clinical laboratory procedures, with the same facility used at both time points. HDL-C was designated as the primary biomarker. Additional blood measures were low-density lipoprotein cholesterol (LDL-C), total cholesterol (TC), triglycerides (TG), glucose, aspartate aminotransferase (AST), alanine aminotransferase (ALT), and γ -glutamyl transferase (γ -GTP). Atherogenic lipid indices were calculated as TC/HDL-C, LDL-C/HDL-C, and TG/HDL-C. Because only the LDL-C/HDL-C ratio showed a significant overall Pre/Post change, that ratio was retained as the principal exploratory lipid index. HDL-C percentage change was defined as $[(\text{Post HDL-C} - \text{Pre HDL-C}) / \text{Pre HDL-C}] \times 100$.

Physical function

At both time points, physical performance was characterized across seven domains using the 30-s chair-stand test (CS-30), handgrip strength, sit-and-reach flexibility, straight-course fast walking over 30 m, directional-change walking over a 10-m zigzag course, single-leg stance with eyes open, and timed rising from supine to standing. Procedures and equipment were kept unchanged between time points. Published evidence supporting the validity, reliability, responsiveness, or established use of these tests in older adults was used where available. Assessment procedures were also informed by a related community multicomponent-exercise study (Motoyama & Motoyama, 2026). The CS-30 followed a procedure with documented validity and responsiveness (Bruun et al., 2019). For one-leg stance, relevant reliability and validity evidence was drawn from recent work in older adults (Omaña et al., 2021; Hao et al., 2023), and the

concept underlying the supine-to-stand assessment was informed by a systematic review linking the task with functional health (Cattuzzo et al., 2020). During the 30-m fast walk, participants covered a level straight course at the fastest pace they could achieve safely, and elapsed time was recorded. The 10-m zigzag task followed a previously reported directional-change walking assessment (Natsume et al., 2021), with participants moving around the outside of designated cones as quickly as possible. For all timed measures, a shorter completion time indicated better performance.

Statistical analyses

Continuous data are summarized as mean $\pm$ standard deviation (SD). Differences among the Low, Intermediate, and High groups in continuous background or exposure variables were examined by one-way analysis of variance, whereas sex distribution was compared with Pearson's chi-square test. Paired *t* tests evaluated within-group Pre/Post change, and one-way analysis of variance was used to compare change scores (Δ) among the three adherence groups. For the primary regression analysis, percentage change in HDL-C served as the outcome. The main predictor was the composite adherence score, with age, sex, and baseline HDL-C entered as covariates. Coefficients are expressed as percentage-point differences in HDL-C percentage change per 1-SD higher adherence value in this sample. Each exercise component was first modeled separately; all three components were then entered together in a simultaneous model. A separate categorical model estimated adjusted contrasts for Intermediate versus Low and High versus Low and also calculated the High-versus-Intermediate contrast. Linear trend across the ordered Low, Intermediate, and High categories was additionally tested. Because secondary and exploratory analyses were not multiplicity-adjusted, their *p* values were interpreted as hypothesis-generating. Statistical tests were two-sided with *p* < 0.05 as the significance threshold. Analyses were conducted in Python with SciPy and statsmodels. For the principal regression models, 95% confidence intervals (CIs) and adjusted R^2 are reported to convey estimate precision and model fit).

Results

The 75 participants had a mean age of 73.2 ± 6.7 years; 50 were women and 25 were men. The Low, Intermediate, and High groups included 15, 32, and 28 participants, respectively. Mean ages were 70.4 ± 5.7 , 75.2 ± 6.7 , and 72.4 ± 6.7 years, respectively, with a significant between-group difference (*p* = 0.046). No significant between-group differences were observed for sex, height, body weight, BMI, or waist circumference. Attendance at supervised sessions was $80.0 \pm 12.5\%$ in the Low group, $88.8 \pm 10.7\%$ in the Intermediate group, and $90.8 \pm 10.7\%$ in the High group, with a significant between-group difference (*p* = 0.011) (Table 1).

Table 1. Participant characteristics according to multicomponent exercise adherence.

Characteristic	Low	Intermediate	High	P value
Age, years	70.4 ± 5.7	75.2 ± 6.7	72.4 ± 6.7	0.046
Sex, women/men	12/3	21/11	17/11	0.436
Height, cm	158.3 ± 8.7	159.4 ± 6.8	158.7 ± 8.5	0.872
Weight, kg	59.5 ± 9.8	58.1 ± 9.1	55.8 ± 11.6	0.488
BMI, kg/m ²	23.7 ± 2.8	22.8 ± 2.8	22.1 ± 3.6	0.268
Waist circumference, cm	88.2 ± 5.1	86.0 ± 7.9	84.1 ± 10.5	0.320
Attendance rate, %	80.0 ± 12.5	88.8 ± 10.7	90.8 ± 10.7	0.011

Note. Values are mean $\pm$ SD. *P* values for continuous variables were obtained by one-way ANOVA; sex distribution was compared using Pearson's chi-square test. Groups: Low = 0 diary-based criteria achieved; Intermediate = 1–2 criteria achieved; High = all 3 criteria achieved. Criteria: step exercise ≥ 60 min/week, resistance exercise ≥ 5 equivalent days/week, and stretching ≥ 5 equivalent days/week. BMI = body mass index; SD = standard deviation.

Diary-derived step-exercise duration was 31.6 ± 13.4 , 60.3 ± 20.2 , and 86.8 ± 25.1 min/week in the Low, Intermediate, and High groups, respectively. Resistance-exercise frequency was 2.58 ± 1.28 , 4.58 ± 1.54 , and 6.32 ± 0.49 equivalent days/week, and stretching frequency was 3.54 ± 1.20 , 4.96 ± 1.62 , and 6.43 ± 0.48 equivalent days/week, respectively; all three measures differed significantly across groups (all $p < 0.001$). In contrast, daily step counts during the intervention did not differ significantly among groups (4782 ± 2112 , 5056 ± 2385 , and 5992 ± 2443 steps/day; $p = 0.193$). At 12 weeks, questionnaire-reported aerobic-related physical activity did not differ among groups ($p = 0.967$), whereas resistance-exercise duration ($p = 0.011$) and stretching duration ($p = 0.003$) did (Table 2).

Table 2. Exercise exposure and self-reported exercise behavior.

Variable	Low	Intermediate	High	P value
Step exercise during intervention, min/week	31.6 ± 13.4	60.3 ± 20.2	86.8 ± 25.1	<0.001
Resistance exercise during intervention, equivalent days/week	2.58 ± 1.28	4.58 ± 1.54	6.32 ± 0.49	<0.001
Stretching during intervention, equivalent days/week	3.54 ± 1.20	4.96 ± 1.62	6.43 ± 0.48	<0.001
Daily steps during intervention, steps/day	4782 ± 2112	5056 ± 2385	5992 ± 2443	0.193
Aerobic-related activity at baseline, min/week	336.3 ± 387.0	532.3 ± 556.2	568.4 ± 427.4	0.301
Aerobic-related activity at 12 weeks, min/week	570.4 ± 830.5	561.9 ± 454.2	534.3 ± 273.7	0.967
Resistance exercise at baseline, min/week	33.0 ± 55.5	45.2 ± 56.8	73.4 ± 80.7	0.117
Resistance exercise at 12 weeks, min/week	73.0 ± 76.9	97.8 ± 69.3	153.0 ± 110.3	0.011
Stretching at baseline, min/week	35.7 ± 39.9	68.8 ± 76.9	69.2 ± 98.0	0.362
Stretching at 12 weeks, min/week	55.4 ± 58.3	85.0 ± 70.1	143.4 ± 106.2	0.003

Note. Values are mean $\pm$ SD. P values were obtained by one-way ANOVA. Diary-derived variables summarize the 84-day intervention period; daily steps are presented descriptively and were not included in the composite adherence score. Questionnaire-derived variables are shown for baseline and 12 weeks. SD = standard deviation.

In the full sample, HDL-C increased from 70.2 ± 17.0 to 74.3 ± 18.6 mg/dL, with a mean change of $+4.1 \pm 8.0$ mg/dL ($p < 0.001$). LDL-C ($n = 75$) changed from 130.7 ± 33.1 to 131.0 ± 31.1 mg/dL (change $+0.3 \pm 16.5$ mg/dL, $p = 0.878$), and TG ($n = 75$) changed from 104.3 ± 39.4 to 106.1 ± 47.9 mg/dL (change $+1.8 \pm 38.6$ mg/dL, $p = 0.687$); neither change was significant. Glucose ($n = 74$), AST, ALT, and γ -GTP (each $n = 75$) also showed no significant changes. In contrast, TC ($n = 72$) increased from 220.2 ± 37.2 to 228.9 ± 38.2 mg/dL (change $+8.8 \pm 21.4$ mg/dL, $p < 0.001$). The LDL-C/HDL-C ratio ($n = 75$) decreased from 1.96 ± 0.63 to 1.86 ± 0.60 (change -0.10 ± 0.34 , $p = 0.012$) (Table 3).

Table 3. Pre-post changes in selected blood markers and a significant atherogenic index in the entire exercise group.

Blood marker	n	Pre	Post	Change	Paired p
HDL-C, mg/dL	75	70.2 ± 17.0	74.3 ± 18.6	4.1 ± 8.0	<0.001
LDL-C, mg/dL	75	130.7 ± 33.1	131.0 ± 31.1	0.3 ± 16.5	0.878
Total cholesterol, mg/dL	72	220.2 ± 37.2	228.9 ± 38.2	8.8 ± 21.4	<0.001
Triglycerides, mg/dL	75	104.3 ± 39.4	106.1 ± 47.9	1.8 ± 38.6	0.687
Glucose, mg/dL	74	103.1 ± 22.4	107.3 ± 22.3	4.2 ± 22.4	0.111
AST, U/L	75	22.8 ± 9.4	23.8 ± 6.4	1.0 ± 5.5	0.122
ALT, U/L	75	18.4 ± 8.8	19.5 ± 8.5	1.1 ± 5.6	0.101
γ -GTP, U/L	75	27.3 ± 22.3	29.0 ± 30.8	1.7 ± 13.9	0.280
LDL-C/HDL-C ratio	75	1.96 ± 0.63	1.86 ± 0.60	-0.10 ± 0.34	0.012

Note. Values are mean $\pm$ SD. Paired p values were obtained with paired t tests. HDL-C was the primary biomarker. Among the examined atherogenic indices (TC/HDL-C, LDL-C/HDL-C, and TG/HDL-C), only the LDL-C/HDL-C ratio showed a significant overall Pre/Post change and is therefore shown here. HDL-C = high-density lipoprotein cholesterol; LDL-C =

low-density lipoprotein cholesterol; TC = total cholesterol; TG = triglycerides; AST = aspartate aminotransferase; ALT = alanine aminotransferase; γ -GTP = gamma-glutamyl transferase; SD = standard deviation.

In the Low group, HDL-C changed from 68.9 ± 11.0 to 66.4 ± 11.1 mg/dL, with a mean change of -2.5 mg/dL that was not significant ($p = 0.284$). In contrast, HDL-C increased from 69.3 ± 17.6 to 74.4 ± 19.5 mg/dL in the Intermediate group (mean change $+5.1$ mg/dL, $p < 0.001$) and from 71.9 ± 19.2 to 78.5 ± 19.8 mg/dL in the High group (mean change $+6.6$ mg/dL, $p < 0.001$). The difference in change among the three groups was significant ($p < 0.001$).

Changes in LDL-C, TG, glucose, ALT, and γ -GTP did not differ significantly among the three groups. Within the High group, AST increased from 22.7 ± 7.2 to 24.7 ± 6.3 U/L ($p = 0.041$), but the between-group difference in change was not significant ($p = 0.471$). TC increased within the High group from 213.0 ± 33.7 to 226.7 ± 35.0 mg/dL ($p < 0.001$), but the between-group difference in change was not significant ($p = 0.207$). The LDL-C/HDL-C ratio decreased in the Intermediate group (2.01 ± 0.59 to 1.86 ± 0.54 , $p = 0.005$) and the High group (1.84 ± 0.65 to 1.71 ± 0.57 , $p = 0.008$), whereas the between-group difference in change was not significant ($p = 0.178$) (Table 4).

Table 4. Selected blood markers and LDL-C/HDL-C ratio according to the three adherence groups.

Blood marker	Low			Intermediate			High			P between
	Pre	Post	Within p	Pre	Post	Within p	Pre	Post	Within p	
HDL-C, mg/dL	68.9 ± 11.0	66.4 ± 11.1	0.284	69.3 ± 17.6	74.4 ± 19.5	<0.001	71.9 ± 19.2	78.5 ± 19.8	<0.001	<0.001
LDL-C, mg/dL	138.6 ± 37.1	135.8 ± 33.4	0.630	133.7 ± 33.8	132.8 ± 33.8	0.766	123.2 ± 29.6	126.5 ± 26.9	0.189	0.453
Total cholesterol, mg/dL	225.4 ± 37.2	226.9 ± 35.5	0.825	223.9 ± 40.4	231.9 ± 43.1	0.056	213.0 ± 33.7	226.7 ± 35.0	<0.001	0.207
Triglycerides, mg/dL	98.5 ± 29.4	110.0 ± 53.9	0.505	113.0 ± 40.7	112.3 ± 44.1	0.904	97.4 ± 41.7	96.8 ± 49.0	0.906	0.557
Glucose, mg/dL	103.1 ± 19.9	105.2 ± 20.5	0.383	104.0 ± 22.0	110.7 ± 27.5	0.113	102.2 ± 24.8	104.7 ± 16.2	0.627	0.705
AST, U/L	21.8 ± 4.6	21.7 ± 3.3	0.947	23.3 ± 12.5	24.0 ± 7.4	0.582	22.7 ± 7.2	24.7 ± 6.3	0.041	0.471
ALT, U/L	17.7 ± 5.7	18.1 ± 6.9	0.833	18.5 ± 11.1	19.5 ± 10.8	0.226	18.7 ± 7.2	20.2 ± 6.1	0.221	0.821
γ -GTP, U/L	37.1 ± 22.8	39.7 ± 28.2	0.440	27.3 ± 26.7	30.1 ± 40.6	0.437	22.0 ± 14.1	22.2 ± 13.3	0.637	0.757
LDL-C/HDL-C ratio (atherogenic index)	2.07 ± 0.68	2.12 ± 0.71	0.766	2.01 ± 0.59	1.86 ± 0.54	0.005	1.84 ± 0.65	1.71 ± 0.57	0.008	0.178

Note. Values are mean $\pm$ SD. Within-group p values were obtained with paired t tests. P between Δ compares Pre/Post change across the three groups by one-way ANOVA. Analyses used available paired data (total $n = 72$ for TC, $n = 74$ for glucose, and $n = 75$ for the other blood markers). HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; TC = total cholesterol; TG = triglycerides; AST = aspartate aminotransferase; ALT = alanine aminotransferase; γ -GTP = gamma-glutamyl transferase; SD = standard deviation.

CS-30 performance improved in all three groups: from 23.5 ± 5.3 to 29.1 ± 5.8 repetitions in the Low group, from 20.9 ± 5.4 to 29.2 ± 6.0 repetitions in the Intermediate group, and from 21.2 ± 5.0 to 31.1 ± 6.1 repetitions in the High group (all $p < 0.001$). The between-group difference in change was also significant ($p = 0.024$). Grip-strength change differed among groups ($p = 0.012$), although no group showed a significant within-group improvement. The 30-m fast walk improved in all three groups. The 10-m zigzag walk, one-leg standing, and supine-to-stand time also improved in multiple groups; however, between-group differences in change were not significant for these outcomes (Table 5).

After adjustment for age, sex, and baseline HDL-C, each 1-SD increase in the composite exercise-adherence score was associated with a 5.23-percentage-point greater percentage change in HDL-C (95% CI 2.70–7.76, $p < 0.001$; adjusted $R^2 = 0.215$). In separate single-component models, the coefficients were +3.74 percentage points for step exercise (95% CI 1.04–6.43, $p = 0.007$), +5.05 percentage points for resistance

exercise (95% CI 2.50–7.61, $p < 0.001$), and +4.12 percentage points for stretching (95% CI 1.49–6.75, $p = 0.003$). In the simultaneous three-component model, the coefficients were +1.14 percentage points for step exercise (95% CI -2.12–4.41, $p = 0.488$), +3.27 percentage points for resistance exercise (95% CI -0.60–7.14, $p = 0.097$), and +1.78 percentage points for stretching (95% CI -1.44–5.00, $p = 0.275$); none was statistically significant (Table 6, Figure 2).

The overall adjusted effect of the three-group model was significant ($p = 0.002$). With the Low group as the reference, the adjusted difference was +9.30 percentage points for the Intermediate group (95% CI 2.08–16.51, $p = 0.012$) and +13.18 percentage points for the High group (95% CI 5.96–20.40, $p < 0.001$). The High versus Intermediate contrast was +3.88 percentage points (95% CI -2.01–9.77, $p = 0.193$) and was not significant. The adjusted linear trend across Low → Intermediate → High was +6.20 percentage points per level (95% CI 2.68–9.73, $p < 0.001$) (Table 6, Figure 1A). The ordinal trend across the number of diary-based adherence criteria achieved (0–3) also remained significant after adjustment for age, sex, and baseline HDL-C ($p < 0.001$) (Figure 1B).

Table 5. Physical-function changes according to the three adherence groups.

Outcome	Low			Intermediate			High			p between
	Pre	Post	Within p	Pre	Post	Within p	Pre	Post	Within p	
30-s chair-stand, reps	23.5 ± 5.3	29.1 ± 5.8	<0.001	20.9 ± 5.4	29.2 ± 6.0	<0.001	21.2 ± 5.0	31.1 ± 6.1	<0.001	0.024
Grip strength, kg	24.8 ± 6.2	22.1 ± 8.7	0.095	25.2 ± 5.8	25.5 ± 6.8	0.513	25.9 ± 7.1	26.1 ± 7.3	0.522	0.012
Sit-and-reach, cm	35.0 ± 8.6	33.5 ± 9.3	0.485	32.9 ± 9.6	32.1 ± 10.7	0.534	31.6 ± 9.8	33.9 ± 10.7	0.051	0.119
30-m fast walk, s	12.24 ± 2.53	10.38 ± 1.68	0.003	14.22 ± 2.34	12.33 ± 3.32	<0.001	13.07 ± 1.56	11.08 ± 1.78	<0.001	0.965
10-m zigzag walk, s	6.55 ± 0.96	6.04 ± 0.74	0.016	7.09 ± 1.17	6.78 ± 1.20	0.074	6.88 ± 0.92	6.39 ± 0.87	0.001	0.663
One-leg standing, s	52.6 ± 11.4	59.0 ± 3.7	0.065	39.0 ± 20.6	48.8 ± 17.4	0.005	41.8 ± 22.1	54.9 ± 13.7	0.003	0.525
Supine-to-stand, s	3.16 ± 0.84	2.85 ± 0.62	0.233	3.56 ± 1.76	3.16 ± 0.89	0.079	3.20 ± 1.02	2.83 ± 0.78	0.008	0.962

Note. Values are mean ± SD. Within-group p values were obtained with paired t tests. P between Δ compares Pre/Post change across groups by one-way ANOVA. Lower values indicate improvement for timed walking and supine-to-stand tests. CS-30 = 30-s chair-stand test; SD = standard deviation.

Table 6. Adjusted regression models for HDL-C percentage change.

Model	Predictor	β (95% CI)	P value	Adjusted R ²
Composite model	Composite adherence score (per 1 SD)	5.23 (2.70 to 7.76)	<0.001	0.215
Single-component	Step exercise (per 1 SD)	3.74 (1.04 to 6.43)	0.007	0.121
Single-component	Resistance exercise (per 1 SD)	5.05 (2.50 to 7.61)	<0.001	0.202
Single-component	Stretching (per 1 SD)	4.12 (1.49 to 6.75)	0.003	0.144
Simultaneous components	Step exercise (per 1 SD)	1.14 (-2.12 to 4.41)	0.488	0.197
Simultaneous components	Resistance exercise (per 1 SD)	3.27 (-0.60 to 7.14)	0.097	0.197
Simultaneous components	Stretching (per 1 SD)	1.78 (-1.44 to 5.00)	0.275	0.197
Three-group model	Intermediate vs Low	9.30 (2.08 to 16.51)	0.012	0.170
Three-group model	High vs Low	13.18 (5.96 to 20.40)	<0.001	0.170
Three-group model	High vs Intermediate	3.88 (-2.01 to 9.77)	0.193	0.170

Note. All models were adjusted for age, sex, and baseline HDL-C. Overall adjusted three-group effect: $p = 0.002$. Adjusted linear trend across Low, Intermediate, and High: $\beta = 6.20$ percentage points per level (95% CI 2.68–9.73), $p < 0.001$. β = regression coefficient; CI = confidence interval; SD = standard deviation; R² = coefficient of determination; HDL-C = high-density lipoprotein cholesterol.

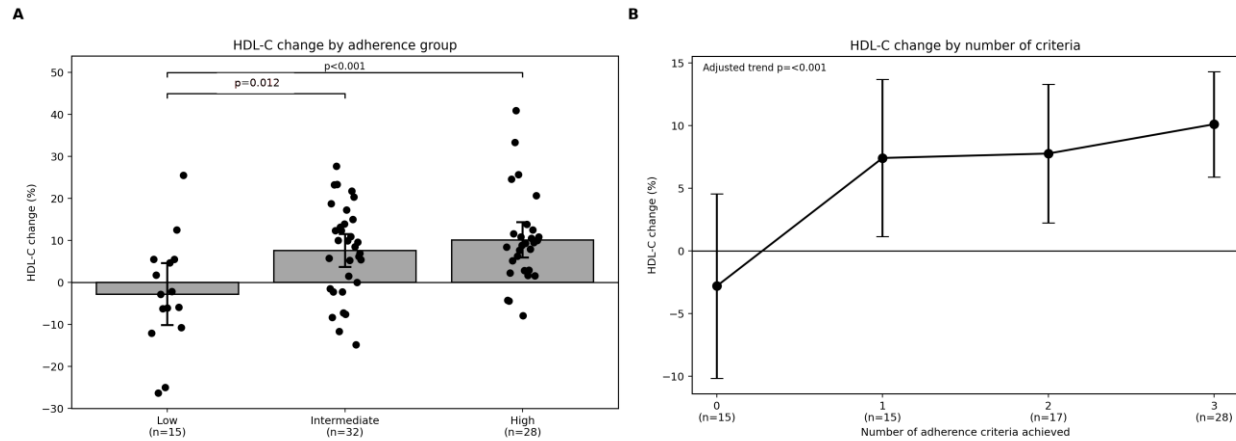


Figure 1. HDL-C percentage change according to adherence groups and number of adherence criteria achieved.

Note. Panel A shows HDL-C percentage change across the three adherence groups. Bars show mean values with 95% confidence intervals; individual values are overlaid. Overall adjusted group effect: $p = 0.002$; adjusted linear trend across Low, Intermediate, and High: $p < 0.001$. Adjusted pairwise comparisons: Intermediate vs Low, $p = 0.012$; High vs Low, $p < 0.001$. Panel B shows HDL-C percentage change according to the number of achieved diary-based adherence criteria (0–3). The ordered trend remained significant after adjustment for age, sex, and baseline HDL-C ($p < 0.001$).

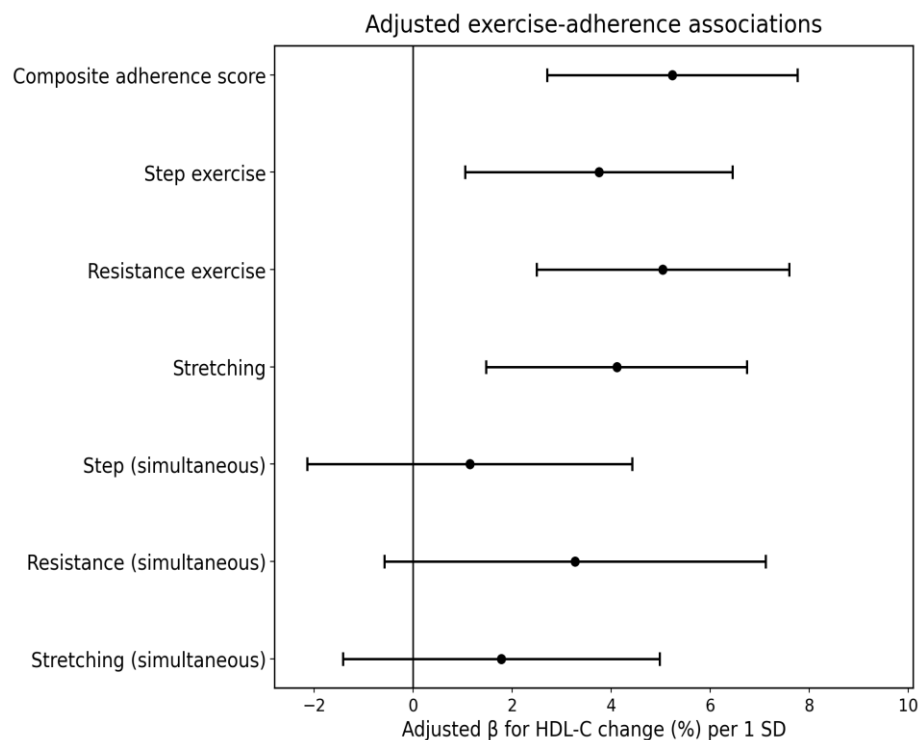


Figure 2. Adjusted regression coefficients for exercise adherence and HDL-C percentage change.

Note. Points represent regression coefficients and horizontal error bars represent 95% confidence intervals. All models were adjusted for age, sex, and baseline HDL-C. Coefficients are expressed per 1-SD increase in each exercise-adherence variable. The simultaneous model included step exercise, resistance exercise, and stretching together. The vertical line at 0 indicates the null value. HDL-C = high-density lipoprotein cholesterol; SD = standard deviation.

Discussion

This study found that, among community-dwelling older adults participating in a 12-week multicomponent exercise program, greater exercise adherence quantified from an 84-day diary was associated with a larger HDL-C response. HDL-C did not change significantly in the Low group, whereas it increased in the Intermediate and High groups, and both groups showed a greater percentage change in HDL-C than the Low group after adjustment for age, sex, and baseline HDL-C. A positive association was also observed when adherence was analyzed as a continuous composite score rather than by exploratory group classification. Thus, the principal finding was supported by both categorical and continuous measures of actual exercise exposure.

These findings are broadly consistent with recent evidence that exercise training can improve HDL-C. In a meta-analysis of 148 randomized controlled trials, Smart et al. (2025) reported a mean HDL-C increase of 2.11 mg/dL (95% CI 1.43–2.79) with exercise training. A meta-analysis restricted to older adults also found a significant increase in HDL-C with aerobic exercise (Yun et al., 2023). In East Asian populations, the mean increase has been reported to be approximately 2.2 mg/dL, with potentially larger responses at ≥ 150 min/week and with moderate-intensity exercise (Igarashi et al., 2019). A recent systematic review and meta-analysis in middle-aged and older individuals likewise supports improvement in HDL-C with regular exercise (Liang et al., 2025). In the present study, mean HDL-C increased by +4.1 mg/dL overall and by +5.1 and +6.6 mg/dL in the Intermediate and High groups, respectively. These changes were larger than the average increases reported in recent meta-analyses (Igarashi et al., 2019; Smart et al., 2025). However, because this study lacked a non-exercise control group, the absolute changes cannot be directly interpreted as the causal effect of the multicomponent exercise program. The more informative observation is that, within the same program, participants with greater actual multicomponent exercise exposure exhibited larger HDL-C responses.

The Intermediate group also showed a significantly greater HDL-C percentage change than the Low group, whereas the difference between the High and Intermediate groups was not significant. Therefore, the exploratory thresholds used in this study—step exercise ≥ 60 min/week, resistance exercise ≥ 5 equivalent days/week, and stretching ≥ 5 equivalent days/week—should not be interpreted as general exercise recommendations for older adults. Rather, a notable finding was that a larger HDL-C response was already apparent in the Intermediate group, which maintained one or two exercise components above the study-defined thresholds, compared with the Low group. The results therefore do not indicate that performing every exercise component at a high frequency is necessarily better; instead, they support the practical importance of incorporating and sustaining multiple exercise components in a feasible manner according to individual fitness and pre-existing exercise habits. Step exercise, resistance exercise, and stretching were each significantly associated with HDL-C percentage change when entered separately, whereas none retained statistical significance when all three were entered simultaneously. This pattern may reflect overlap among participants who frequently performed the three exercise components and shared variance across the adherence measures. The limited sample size may also have reduced the precision with which independent associations for the individual components could be estimated. Accordingly, the present results do not allow the independent contribution of each exercise component to be clearly distinguished. Recent meta-analyses also indicate that lipid responses may differ across aerobic, resistance, and combined exercise modalities and may vary according to participant characteristics and exercise prescription (Yun et al., 2023; Smart et al., 2025; Hejazi et al., 2025). The findings should therefore be interpreted as showing an association between HDL-C response and overall adherence to a program involving multiple exercise components rather than superiority of any single component.

Several physiological mechanisms may underlie the larger HDL-C response observed in participants with greater exercise exposure and consistency. Increased energy expenditure and exercise-induced changes in

lipid metabolism may promote the metabolism of triglyceride-rich lipoproteins and contribute to quantitative and qualitative changes in HDL particles (Ruiz-Ramie et al., 2019; Franczyk et al., 2023). Exercise may also improve HDL maturation and remodeling, cholesterol efflux capacity, antioxidant activity, and anti-inflammatory function (Ruiz-Ramie et al., 2019; Franczyk et al., 2023). These mechanisms were not measured directly in the present study, and the independent effect of exercise frequency itself has not been established; therefore, the present results cannot be used to infer causally that greater exercise volume or frequency reduces cardiovascular risk. In addition, blood markers other than HDL-C did not show the same clear graded pattern across adherence groups. Although the LDL-C/HDL-C ratio decreased in the full sample, the between-group difference in change was not significant, and TC increased overall. HDL function may be as important as concentration, and a recent systematic review and meta-analysis linked greater cholesterol efflux capacity and antioxidant and anti-inflammatory HDL functions with lower cardiovascular and mortality risk (Soria-Flórido et al., 2020). Thus, the observed increase in HDL-C may represent a favorable lipid response to exercise, but it should not be interpreted as direct evidence of reduced atherosclerotic risk or fewer cardiovascular events. Future studies should incorporate HDL particle characteristics, cholesterol efflux capacity, inflammatory and oxidative-stress markers, and direct measures of atherosclerosis.

Several physical-function measures, including CS-30 and walking performance, improved, broadly consistent with recent systematic reviews and meta-analyses supporting multicomponent exercise for physical function in older adults (Labata-Lezaun et al., 2023; Li et al., 2023; Alowaydhah et al., 2024; Toosi et al., 2026) and with reports of community- and home-based exercise programs (Chaabene et al., 2021; Mañas et al., 2021; Motoyama & Motoyama, 2026). However, the graded association with adherence observed for HDL-C was not seen across all physical-function outcomes. Participants also reported substantial aerobic-related physical activity at baseline— 336.3 ± 387.0 , 532.3 ± 556.2 , and 568.4 ± 427.4 min/week in the Low, Intermediate, and High groups, respectively—and daily step counts during the intervention did not differ significantly among groups. These observations suggest that, for community-dwelling older adults who already engage in health-promoting activities such as walking, a practical strategy may be to maintain aerobic activity while consistently incorporating multicomponent exercise involving strength, balance, and flexibility rather than focusing only on increasing step counts. The Japanese Physical Activity Guide for Health Promotion 2023 recommends multicomponent exercise at least 3 days/week and resistance exercise 2–3 days/week in older adults (Ministry of Health, Labour and Welfare, 2024), while the WHO recommends 150–300 min/week of moderate-intensity aerobic physical activity, muscle-strengthening activity on at least 2 days/week, and multicomponent activity emphasizing functional balance and strength on at least 3 days/week (World Health Organization, 2020). The present study did not test these guideline thresholds directly but supports the potential value of adding and sustaining multiple exercise components alongside existing exercise habits.

A strength of this study was the daily recording of three exercise components over 84 days and the evaluation of their association with HDL-C response using both a continuous composite score and an exploratory three-group classification. Several limitations should also be acknowledged. First, the single-arm design without a non-exercise control group precludes definitive causal inference and cannot fully separate intervention-related changes from natural or seasonal variation, medication effects, or other lifestyle factors. Participants were instructed not to intentionally change dietary content or intake, but diet could not be fully controlled under free-living conditions, leaving the possibility of residual confounding. Second, exercise exposure was based on self-reported diaries and may therefore be affected by recording error or reporting bias. Third, age and supervised-session attendance differed across the three groups. Although the primary regression analyses adjusted for age, sex, and baseline HDL-C, unmeasured confounding related to health consciousness or lifestyle may remain. Fourth, the Low group included only 15 participants, limiting the precision of between-group estimates. Fifth, the thresholds of 60 min/week, 5 equivalent days/week, and 5 equivalent days/week were exploratory criteria established within this study and should not be interpreted as general recommendations or thresholds for improving HDL-C. Finally, no multiplicity correction was applied

to secondary or exploratory analyses, and these findings should therefore be considered hypothesis-generating. Future controlled studies should include objective physical-activity measures and dietary assessment and examine the relationship between specific doses of multicomponent exercise and HDL-C response, as well as HDL function and direct atherosclerosis-related outcomes, including in older adults who already have established physical-activity habits.

Conclusion

In this 12-week community-based multicomponent exercise program combining weekly supervised group exercise with home-based step exercise, resistance exercise, and stretching, greater multicomponent exercise adherence quantified from an 84-day diary was associated with a larger increase in HDL-C. Similar associations were observed using both the continuous composite adherence score and the exploratory three-group analysis, suggesting that even among older adults who already engage in some physical activity, sustained participation in multiple exercise components in addition to routine walking may be associated with a more favorable HDL-C response. However, the group thresholds were exploratory and do not establish specific recommended doses or causal effects; controlled studies are needed to clarify these issues.

Practical Application

In community health-promotion programs for older adults, monitoring attendance alone may be insufficient; tracking continued performance of multiple components such as home-based step exercise, resistance exercise, and stretching may provide useful information. Municipal health services and exercise professionals may support participants in sustaining several exercise components at feasible levels according to their existing physical-activity habits and functional capacity, with diaries or similar tools used to monitor adherence. The exploratory thresholds used in this study should not be applied as general exercise recommendations or as HDL-C improvement cutoffs.

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Conflict of Interest: The work was undertaken within a joint research agreement involving Tsuno Rice Fine Chemicals Co., Ltd. and Wakayama University. Apart from this institutional research relationship, the authors report no other conflicts of interest.

Data availability: Because the dataset contains information that could implicate participant privacy, the study data are not publicly posted. De-identified data and analysis code may be provided by the corresponding author in response to a reasonable request, provided that such sharing is permitted by the Wakayama University Ethics Committee and by applicable ethical and legal requirements.

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Declaration of generative AI and AI-assisted technologies in the writing process: ChatGPT (OpenAI) was used during manuscript preparation for organization of the paper, refinement of English wording, organization of reported statistical results, and cross-checking consistency among the manuscript, tables, and figures. All source research materials and analytic results were supplied by the authors. The authors subsequently reviewed and edited the AI-assisted content and accept full responsibility for the final publication.

References

- Alowaydhah, S., Weerasekara, I., Walmsley, S., & Marquez, J. (2024). Physical exercise for healthy older adults and those with frailty: What exercise is best and is there a difference? A systematic review and meta-analyses. *Current Gerontology and Geriatrics Research*, 2024, 5639004. <https://doi.org/10.1155/2024/5639004>
- Bruun, I. H., Mogensen, C. B., Nørgaard, B., Schiøttz-Christensen, B., & Maribo, T. (2019). Validity and responsiveness to change of the 30-second chair-stand test in older adults admitted to an emergency department. *Journal of Geriatric Physical Therapy*, 42(4), 265–274. <https://doi.org/10.1519/JPT.0000000000000166>
- Cattuzzo, M. T., de Santana, F. S., Safons, M. P., Ré, A. H. N., Nesbitt, D. R., Santos, A. B. D., Feitoza, A. H. P., & Stodden, D. F. (2020). Assessment in the supine-to-stand task and functional health from youth to old age: A systematic review. *International Journal of Environmental Research and Public Health*, 17(16), 5794. <https://doi.org/10.3390/ijerph17165794>
- Chaabene, H., Prieske, O., Herz, M., Moran, J., Höhne, J., Kliegl, R., Ramirez-Campillo, R., Behm, D. G., Hortobágyi, T., & Granacher, U. (2021). Home-based exercise programmes improve physical fitness of healthy older adults: A PRISMA-compliant systematic review and meta-analysis with relevance for COVID-19. *Ageing Research Reviews*, 67, 101265. <https://doi.org/10.1016/j.arr.2021.101265>
- dos Santos, I. K., Cobucci, R. N., de Medeiros, J. A., de Assis, G. G., da Silva Cunha de Medeiros, R. C., Knackfuss, M. I., de Araújo Tinoco Cabral, B. G., dos Santos, R. V. T., & Dantas, P. M. S. (2024). Home-based indoor physical activity programs for community-dwelling older adults: A systematic review. *Sports Health*, 16(3), 377–382. <https://doi.org/10.1177/19417381231175665>
- Franczyk, B., Gluba-Brzózka, A., Ciałkowska-Rysz, A., Ławiński, J., & Rysz, J. (2023). The impact of aerobic exercise on HDL quantity and quality: A narrative review. *International Journal of Molecular Sciences*, 24(5), 4653. <https://doi.org/10.3390/ijms24054653>
- Hao, Q., Kuspinar, A., Griffith, L., D'Amore, C., Mayhew, A. J., Wolfson, C., Guyatt, G., Raina, P., & Beauchamp, M. (2023). Measuring physical performance in later life: Reliability of protocol variations for common performance-based mobility tests. *Ageing Clinical and Experimental Research*, 35(5), 1087–1096. <https://doi.org/10.1007/s40520-023-02384-0>
- Hejazi, K., Iraj, Z. A., Saeidi, A., Hackney, A. C., Laziri, F., Suzuki, K., Laher, I., & Hassane, Z. (2025). Differential effects of exercise training protocols on blood pressures and lipid profiles in older adults patients with hypertension: A systematic review and meta-analysis. *Archives of Gerontology and Geriatrics*, 131, 105737. <https://doi.org/10.1016/j.archger.2024.105737>
- Igarashi, Y., Akazawa, N., & Maeda, S. (2019). Effects of aerobic exercise alone on lipids in healthy East Asians: A systematic review and meta-analysis. *Journal of Atherosclerosis and Thrombosis*, 26(5), 488–503. <https://doi.org/10.5551/jat.45864>
- Izquierdo, M., Merchant, R. A., Morley, J. E., Anker, S. D., Aprahamian, I., Arai, H., Aubertin-Leheudre, M., Bernabei, R., Cadore, E. L., Cesari, M., Chen, L.-K., de Souto Barreto, P., Duque, G., Ferrucci, L., Fielding, R. A., García-Hermoso, A., Gutiérrez-Robledo, L. M., Harridge, S. D. R., Kirk, B., Kritchevsky, S., Landi, F., Lazarus, N., Martin, F. C., Marzetti, E., Pahor, M., Ramírez-Vélez, R., Rodríguez-Mañas, L., Rolland, Y., Ruiz, J. G., Theou, O., Villareal, D. T., Waters, D. L., Won Won, C., Woo, J., Vellas, B., & Fiatarone Singh, M. (2021). International exercise recommendations in older adults (ICFSR): Expert consensus guidelines. *The Journal of Nutrition, Health & Aging*, 25(7), 824–853. <https://doi.org/10.1007/s12603-021-1665-8>
- Labata-Lezaun, N., González-Rueda, V., Llorca-Almuzara, L., López-de-Celis, C., Rodríguez-Sanz, J., Bosch, J., Vicente-Rodríguez, G., Gorczakowska, D., Araluz-Arizti, P., & Pérez-Bellmunt, A. (2023). Effectiveness of multicomponent training on physical performance in older adults: A systematic review and meta-analysis. *Archives of Gerontology and Geriatrics*, 104, 104838. <https://doi.org/10.1016/j.archger.2022.104838>
- Li, Y., Gao, Y., Hu, S., Chen, H., Zhang, M., Yang, Y., & Liu, Y. (2023). Effects of multicomponent exercise on the muscle strength, muscle endurance and balance of frail older adults: A meta-analysis of randomised controlled trials. *Journal of Clinical Nursing*, 32(9–10), 1795–1805. <https://doi.org/10.1111/jocn.16196>
- Liang, L., Peng, F., Wang, L., Lin, C., & Chi, H. (2025). Effects of exercise on high-density lipoprotein levels in middle-aged and older individuals: A systematic review and meta-analysis. *Medicine*, 104(6), e41493. <https://doi.org/10.1097/MD.00000000000041493>
- Mañas, A., Gómez-Redondo, P., Valenzuela, P. L., Morales, J. S., Lucía, A., & Ara, I. (2021). Unsupervised home-based resistance training for community-dwelling older adults: A systematic review and meta-analysis of randomized controlled trials. *Ageing Research Reviews*, 69, 101368. <https://doi.org/10.1016/j.arr.2021.101368>
- Marçal, I. R., Fernandes, B., do Amaral, V. T., Pelaquim, R. L., & Ciolac, E. G. (2022). Prescribing and self-regulating heated water-based exercise by rating of perceived exertion in older individuals with hypertension. *Journal of Aging and Physical Activity*, 30(5), 747–752. <https://doi.org/10.1123/japa.2021-0191>

- Ministry of Health, Labour and Welfare. (2024). *Physical Activity Guide for Health Promotion 2023*. Ministry of Health, Labour and Welfare. <https://www.mhlw.go.jp/content/001495670.pdf>
- Motoyama, T., & Motoyama, M. (2026). Trainability of physical function and threshold age for decline in frail older women: A 6-year community-based multicomponent exercise program. *Journal of Gerontology and Geriatrics*, 74(1), 7. <https://doi.org/10.3390/jgg74010007>
- Natsume, T., Ozaki, H., Nakagata, T., Yoshihara, T., Kitada, T., Ishihara, Y., Deng, P., Osawa, T., Sawada, S., Kobayashi, H., Machida, S., & Naito, H. (2021). Site-specific muscle loss in the abdomen and anterior thigh in elderly males with locomotive syndrome. *Journal of Sports Science and Medicine*, 20(4), 635–641. <https://doi.org/10.52082/jssm.2021.635>
- Omaña, H., Bezaire, K., Brady, K., Davies, J., Louwagie, N., Power, S., Santin, S., & Hunter, S. W. (2021). Functional reach test, single-leg stance test, and Tinetti performance-oriented mobility assessment for the prediction of falls in older adults: A systematic review. *Physical Therapy*, 101(10), pzab173. <https://doi.org/10.1093/ptj/pzab173>
- Rihova, M., Jandova, T., Vetrovsky, T., Machacova, K., Kramperova, V., Steffl, M., Hospodkova, P., Marchelek-Myśliwiec, M., & Holmerova, I. (2024). Adherence and retention rates to home-based video exercise programs in older adults—systematic review and meta-analysis. *Telemedicine and e-Health*, 30(11), 2649–2661. <https://doi.org/10.1089/tmj.2024.0100>
- Room, J., Hannink, E., Dawes, H., & Barker, K. (2017). What interventions are used to improve exercise adherence in older people and what behavioural techniques are they based on? A systematic review. *BMJ Open*, 7(12), e019221. <https://doi.org/10.1136/bmjopen-2017-019221>
- Ruiz-Ramie, J. J., Barber, J. L., & Sarzynski, M. A. (2019). Effects of exercise on HDL functionality. *Current Opinion in Lipidology*, 30(1), 16–23. <https://doi.org/10.1097/MOL.0000000000000568>
- Smart, N. A., Downes, D., van der Touw, T., Hada, S., Dieberg, G., Pearson, M. J., Wolden, M., King, N., & Goodman, S. P. J. (2025). The effect of exercise training on blood lipids: A systematic review and meta-analysis. *Sports Medicine*, 55(1), 67–78. <https://doi.org/10.1007/s40279-024-02115-z>
- Soria-Flrido, M. T., Schröder, H., Grau, M., Fitó, M., & Lassale, C. (2020). High density lipoprotein functionality and cardiovascular events and mortality: A systematic review and meta-analysis. *Atherosclerosis*, 302, 36–42. <https://doi.org/10.1016/j.atherosclerosis.2020.04.015>
- Stuckenschneider, T., Rüdiger, S., Abeln, V., Askew, C. D., Wollseiffen, P., Schneider, S., & NeuroExercise Study Group. (2020). Rating of perceived exertion—a valid method for monitoring light to vigorous exercise intensity in individuals with subjective and mild cognitive impairment? *European Journal of Sport Science*, 20(2), 261–268. <https://doi.org/10.1080/17461391.2019.1629632>
- Toosi, M., Daneshmandi, H., Mottaghitalab, M., & Zarei, H. (2026). The effects of multicomponent training on functional fitness in older adults: A systematic review and meta-analysis. *Journal of Aging and Physical Activity*, 1–19. <https://doi.org/10.1123/japa.2025-0070>
- World Health Organization. (2020). *WHO guidelines on physical activity and sedentary behaviour*. World Health Organization. <https://www.who.int/publications/i/item/9789240015128>
- Yun, H., Su, W., Zhao, H., Li, H., Wang, Z., Cui, X., Xi, C., Gao, R., Sun, Y., & Liu, C. (2023). Effects of different exercise modalities on lipid profile in the elderly population: A meta-analysis. *Medicine*, 102(29), e33854. <https://doi.org/10.1097/MD.00000000000033854>