Author(s): Camacho-Cardenosa, Alba; Amaro-Gahete, Francisco J.; Martinez-Tellez, Borja; Alcantara, Juan M. A.; Ortega, Francisco B.; Ruiz, Jonatan R.

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Sex-specific dose–response effects of a 24-week supervised concurrent exercise intervention on cardiorespiratory fitness and muscular strength in young adults: The ACTIBATE randomized controlled trial

Alba Camacho-Cardenosa[1] | **Francisco J. Amaro-Gahete**[2,3,4] | **Borja Martinez-Tellez**[1,3,5] | **Juan M. A. Alcantara**[1,3,6,7] | **Francisco B. Ortega**[1,3,8] | **Jonatan R. Ruiz**[1,3,4]

[1]Department of Physical Education and Sports, Faculty of Sports Science, Sport and Health University Research Institute (iMUDS), University of Granada, Granada, Spain

[2]Department of Physiology, Faculty of Medicine, University of Granada, Granada, Spain

[3]CIBER de Fisiopatología de la Obesidad y Nutrición (CIBEROBN), Instituto de Salud Carlos III, Granada, Spain

[4]Instituto de Investigación Biosanitaria, Ibs.Granada, Granada, Spain

[5]Department of Education, Faculty of Education Sciences and SPORT Research Group (CTS-1024), CERNEP Research Center, University of Almería, Almería, Spain

[6]Department of Health Sciences, Institute for Innovation & Sustainable Food Chain Development, Public University of Navarre, Pamplona, Spain

[7]Navarra Institute for Health Research, IdiSNA, Pamplona, Spain

[8]Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

Correspondence
Alba Camacho-Cardenosa and Jonatan R. Ruiz, Department of Physical Education and Sports, Faculty of Sports Science, Sport and Health University Research Institute (iMUDS), University of Granada, Carretera de Alfacar s/n, 18071 Granada, Spain.
Email: acamachocardenos@ugr.es and ruizj@ugr.es

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Abstract

Concurrent training has been postulated as an appropriate time-efficient strategy to improve physical fitness, yet whether the exercise-induced adaptations are similar in men and women is unknown. An unblinded randomized controlled trial was conducted to investigate sex-specific dose–response effects of a 24-week supervised concurrent exercise training program on cardiorespiratory fitness and muscular strength in young adults. One hundred and forty-four sedentary adults aged 18–25 years were assigned to either (i) a control group ($n=54$), (ii) a moderate intensity exercise group (MOD-EX, $n=46$), or (iii) a vigorous intensity exercise group (VIG-EX, $n=44$) by unrestricted randomization. Cardiorespiratory fitness (VO_{2max}), hand grip strength, and one-repetition maximum of leg press and bench press were evaluated at baseline and after the intervention. A total of 102 participants finished the intervention (Control, $n=36$; 52% women, MOD-EX, $n=37$; 70% women, and VIG-EX, $n=36$; 72% women). In men, VO_{2max} significantly increased in the MOD-EX (~8%) compared with the control group

Alba Camacho-Cardenosa and Francisco J. Amaro-Gahete equally contributed to this work.

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and in the VIG-EX group after the intervention (~6.5%). In women, VO_{2max} increased in the MOD-EX and VIG-EX groups (~5.5%) compared with the control group after the intervention. There was a significant increment of leg press in the MOD-EX (~15.5%) and VIG-EX (~18%) groups compared with the control group (~1%) in women. A 24-week supervised concurrent exercise was effective at improving cardiorespiratory fitness and lower body limbs muscular strength in young women—independently of the predetermined intensity—while only at moderate intensity improved cardiorespiratory fitness in men.

KEYWORDS

aerobic capacity, hand grip strength, leg press, supervised exercise training, women

1 | INTRODUCTION

Physical fitness is considered an important marker of health in both men and women.[1,2] Physical fitness is typically expressed as cardiorespiratory fitness (CRF) as well as muscular strength.[3,4] Epidemiological investigations have revealed a negative correlation between cardiorespiratory fitness (CRF) and the risk of cardiovascular disease (CVD) and overall mortality among healthy individuals as well as in those with preexisting health conditions.[5–8] Likewise, there is strong evidence on that muscular strength is a marker of cardiovascular health[4,9,10] and is inversely and independently associated with all-case mortality in both men[11] and women.[12]

The World Health Organization 2020 guidelines on physical activity recommends both moderate to vigorous aerobic and muscle-strengthening exercises to maintain or even improve physical fitness and, therefore, overall health.[13] A concurrent training (CT) intervention, which combines aerobic and resistance training, seems to be the most appropriate method to maximize physical fitness enhancements.[14–16] In middle-age adults, a 12-week CT program (i.e., moderate intensity aerobic plus resistance training) was effective at increasing cardiorespiratory fitness (VO_{2max}) and muscular strength.[14] Moreover, a CT intervention at moderate-vigorous intensity also improved cardiorespiratory fitness in older men and women.[15] In young men, previous studies obtained slight improvements in cardiorespiratory fitness (~9% of VO_{2max}) and upper and lower body limbs muscular strength (~13% of 1RM) after 8 weeks of moderate intensity (60%–80% of 1RM) CT.[17,18]

Whether these exercise-induced effects on cardiovascular and respiratory systems are similar in men and women has been less explored.[19] Women have, on average, a 15%–25% lower VO_{2max} and anaerobic performance than men,[20] which may be partially explained by the difference in body size and muscle mass.[21] Hence, given the distinct cardiovascular and respiratory physiological traits exhibited by men and women, it could be postulated that the effects of CT on physical fitness might vary between the two sexes.[22] Given the rising involvement of women in physical activity, encompassing both recreational and health-driven pursuits, along with the increasing interest in comprehending the physiological responses in female exercisers, there exists a compelling scientific and practical imperative to ascertain whether the influence of CT on physical fitness demonstrates parallel effects in both male and female populations. Furthermore, previous studies have shown sex differences in determinants and timing of dropout among participants of exercise interventions,[22] suggesting the need to develop more precise approaches for optimizing exercise adoption and adherence in men and women.

Considering the well-documented decline in physical activity levels among the general population,[23] it becomes apparent that young adulthood could serve as a critical juncture for implementing and maintaining healthy exercise routines.[24] There is lack of studies investigating the existence of sex-specific effects of a CT intervention on cardiorespiratory fitness and muscular strength in young adulthood.[25] Furthermore, it is also of interest to better understand whether higher exercise intensities differentially impact physical fitness based on an individual's gender, as this knowledge can contribute to more tailored and effective exercise recommendations for both men and women.

Thus, this study aimed to investigate the sex-specific dose–response effects of a 24-week supervised CT program on cardiorespiratory fitness and muscular strength in young adults. First, we hypothesize that the intervention would effectively enhance physical fitness regardless of the individual's sex, and that vigorous CT yield greater improvements in cardiorespiratory fitness and muscular strength compared to a similar CT intervention conducted at a moderate intensity.

2 | MATERIALS AND METHODS

The current study includes a secondary analysis from the ACTIBATE trial (ACTIBATE, ClinicalTrials.gov, ID: NCT02365129), a randomized controlled trial initially designed to investigate the dose–response effect of a 24-week concurrent exercise intervention on the mass and activity of brown adipose tissue (BAT) in young adults. The study was approved by the University of Granada Ethics Committee on Human Research (n° 924) and by that of the *Servicio Andaluz de Salud*. The study was performed in accordance with the Declaration of Helsinki (2013 revision). All participants gave their written, informed consent to be included. Participant recruitment, and all assessments and interventions were conducted at the Sport and Health Joint University Institute (iMUDS), and at the University Hospital 'Virgen de las Nieves,' both in Granada, Spain. The study was conducted over two consecutive years (from September 2015 to June 2016, and from September 2016 to June 2017). Participants were enrolled in four waves (16–24 participants in each) starting in September–December.

2.1 | Setting and eligibility criteria

One-hundred forty-four young sedentary adults (women $n=98$) aged 18–25 years were recruited to participate in this randomized control trial (clinicaltrial.gov ID: NCT02365129).[26] The inclusion criteria were (i) not to be engaged in an exercise training program during the last 12 weeks, (ii) to have a body mass index (BMI) between 18.5 and 35 kg/m^2, (iii) to have a stable body weight during the last 12 weeks, (iv) to pass a medical examination, (v) not to have any chronic disease, (vi) not to consume tobacco or drugs, (vii) not to complete more than 20 min of moderate-vigorous physical activity distributed on 3 days/week during the previous 12 weeks, and (viii) to sign a written informed consent form after receiving detailed oral information about the study procedures.

2.2 | Procedures

The participants were recruited using local media, social networks, and/or poster placed in different Faculties of the University of Granada. The research team contacted with potentially eligible participants by email or phone, and a personal interview was programmed. Four testing days were conducted in the baseline. A medical examination was performed in order to discard acute and/or chronic pathologies which could be aggravated by exercise training on Day 1. A body composition assessment was conducted on Day 2. A maximal graded treadmill test was performed on Day 3 to assess the cardiorespiratory fitness. On Day 4, an assessment of muscular strength was conducted. The baseline assessments were separated by a maximum of 15 days. We strictly followed the CONSORT statement for improving the reporting parallel group randomized trials (EQUATOR Network: http://www.equator-network.org/reporting-guidelines/consort/; Table S1).

Participants were instructed not to modify their normal routine or their physical activity over the study period. Physical activity was assessed through accelerometry using triaxial accelerometer (ActiGraph GT3X+) that participants wear on their nondominant wrist during 1 week, before and after intervention.

2.3 | Interventions

The study design was a 24-week randomized control trial. After baseline assessment, the participants were allocated into three different groups using a specific simple randomization software, and being the assessment staff blinded throughout the process: (i) a non-exercise control group, (ii) or a CT program based on the international physical activity recommendations[27] at moderate intensity group (MOD-EX group), (iii) or a CT program based on the international physical activity recommendations[27] at vigorous intensity group (VIG-EX group). We followed the Consensus on Exercise Reporting Template (CERT; Table S2) to facilitate the replicability and transparency of the current study.

The training sessions were conducted at the iMUDS being supervised by graduates in Sport Sciences. The training session attendance was carefully controlled. The missed training sessions were replaced on an alternative day. A minimum of 70% of attendance to the training sessions was determined to assess the efficacy of the exercise training intervention. All training sessions started with a dynamic standardized warm-up (~10 min) including joint mobility and compensatory tasks, and finished with a cool-down phase (~10 min) based on active global stretching.

Both MOD-EX and VIG-EX groups performed 3–4 sessions/week of a CT program. The participants of the MOD-EX group completed a total of 150 min/week at 60% of the heart rate reserve of aerobic training, whereas the VIG-EX group performed a total of 75 min/week at 60% of the heart rate reserve and 75 min/week at 80% of the heart rate reserve of aerobic training. Thus, a similar duration for all sessions, independently of the experimental group, was programed. Different ergometers including cycle-ergometer, elliptical ergometer, and treadmill were used. On the other hand, the resistance training was conducted in two of the 3–4 sessions/week. A total of 8–9 global strength exercises (two sets of 10 repetitions) using weight bearing and guided pneumatic machines were programmed at the 50% of 1 repetition maximum for the MOD-EX group, and at the 70% of 1 repetition maximum for the VIG-EX group (i.e., Romanian deadlift, lateral pull down, ½ squat, and bench press, among others). In addition, we prescribed specific compensatory exercises to increase the adherence of the participant avoiding and/or reducing the incidence of injuries. The heart rate and the ratings of perceived exertion were continuously monitored. All participants had the same exercise dose independently of the training frequency. We individually adapted the training load to the participant's fitness level, and we also scheduled a gradual progression of each exercise training program. The exercise training intervention is extensively detailed elsewhere.[28]

2.4 | Outcome measures

2.4.1 | Anthropometric and body composition assessment

We measured anthropometric and body composition outcomes in a fasted state (12-h), avoiding moderate and/or vigorous activity physical activity (24 h and/or 48 h, respectively), and eating a standardized dinner the day before (i.e., egg omelet, and boiled rice with fried tomato). An electronic scale and stadiometer (model 799; Electronic Column Scale) were used to measure the participant's body weight (kg) and body height (cm) with light clothes and barefoot. We calculated the body mass index as body weight (kg)/body height (m).[2] The body composition assessment was performed by dual-energy x-ray absorptiometry (Hologic Wi; Hologic Inc.) and the fat mass and lean mass were obtained.

2.4.2 | Cardiorespiratory fitness assessment

The previous conditions established for the cardiorespiratory fitness assessment were (i) avoiding the consumption of stimulant substances 24 h before the test, (ii) fasting for 3–5 h, and (iii) not performing vigorous and/or moderate physical activity (48 h and/or 24 h, respectively) before the test. The cardiorespiratory fitness outcomes were determined by a maximal graded treadmill (H/P/Cosmos Pulsar treadmill, H/P/Cosmos Sport & Medical GMBH) walking test applying the modified Balke protocol.[28] It started with a warm-up consisting of walking at 3.5 km/h for 1 min and at 4.0 km/h for 2 min. After that, a speed of 5.3 km/h at 0% grade was maintained during 1 min, followed by grade increments of 1% every minute, until participant's volitional extenuation. The gas exchange was continuously measured by indirect calorimetry using an oronasal mask (model 7400; Hans Rudolph Inc) fitted with a preVent™ high flow sensor (Medgraphics Corp). A 3-L syringe was used for the daily flow calibration. Before each maximal graded treadmill test, the gases analyzers were calibrated using two standard gas concentration bottles as recommended by the manufacturers. We averaged volumes whole-body oxygen consumption and carbon dioxide production (VO_2 and VCO_2, respectively) every 5 s using the Breeze Suite software (version 8.1.0.54 SP7, MGC Diagnostic®; Medgraphics Corp). The heart rate was continuously monitored using a Polar RS800CX heart rate monitor linked to a chest-belt H3 sensor (Polar) every 5 s. The rating of perceived exertion (RPE-CR10) was assessed during the last 15 s of each stage and at exhaustion. The VO_{2max} criteria were[29] (i) to show a VO_2 change <100 mL/min in the last 30 sec of the final stage, (ii) to attain a respiratory exchange ratio ≥1.1, and (iii) to reach a heart rate between ±10 beats/min of the theoretical maximal hearth rate. The peak oxygen uptake was considered when these criteria were not attained. A third researcher opinion was considered when a disagreement between the others two was observed. VO_{2max} was expressed in absolute terms (mL/min) and relative to body weight (mL/kg/min).

2.4.3 | Muscular strength assessment

The handgrip strength (expressed in kg) was assessed[30] using a digital hand dynamometer (T.K.K. 5401 Grip-D; Takey). The participants were instructed to continuously squeeze for ~3 s in two attempts for each hand, separated by 1-min rest exerting their maximal force in both cases. The grip spam of the dynamometer was fixed at 5.5 cm for men, and a validated equation based on the hand size was used for women. The sum of the best attempts on left and right hand, respectively, were considered as the total handgrip strength.

One-repetition maximum (1-RM) leg press and bench press (Keiser Sports Health Equipment) strength was estimated by applying a submaximal protocol and using the Wathen equation[31]:

$$\text{Wathen equation} - 1\text{RM} = \text{Submaximal load}\left(\frac{100}{48.8 + 58.8^{-0.075*\text{Number of repetitions}}}\right)$$

Both submaximal protocols started with a warm-up that consisted on 15 repetitions with a load approximating 50% of the estimated 1-RM. After that, the assessment staff established a specific load aiming to reach the muscular failure before the participant completed less than 10 repetitions. If the participants attained 1 or more, but <10 repetitions, the test was suitable for further analysis. A total of three attempts were allowed with 3-min recovery periods between them.

2.5 | Statistical analysis

No a priori power calculation was performed for the current outcomes since this study is based on a secondary analysis from the ACTIBATE study (a randomized controlled trial aiming at investigating the effects of a 24-week CT intervention on brown adipose tissue volume and activity).[26] However, a posteriori power was calculated for primary outcomes (VO_{2max}, hand grip strength, leg and bench press) ranging from 68% to 84%. The statistical power was originally calculated based on the main outcome of the ACTIBATE study (differences of at least 10% in brown adipose tissue volume could be detected) with a power of >80% and an α of 0.05 in a group of 17 participants per study group. To study sex differences, a total of 34 participants (17 men and 17 women) were required for each group. Assuming a maximum loss to follow-up of 30%, 150 participants were thus targeted (i.e., 50 per group).

The distribution of the main outcomes was checked by Q-Q plots and histograms. Considering that these outcomes presented a normal distribution, the descriptive parameters were expressed as mean ± standard deviation. The analyses were conducted following a per protocol approach and, therefore, no imputation methods were applied. A repeated-measures ANOVA was conducted to examine changes in cardiorespiratory fitness and muscular strength across time, between groups, and the interaction (time*group). An analysis of covariance (ANCOVA) was performed to study the change observed in the groups (fixed factor) on physical fitness outcomes, for example, post-VO_{2max} minus pre-VO_{2max} (dependent variable), adjusting for the baseline values. Similar analyses were conducted for the rest of physical fitness outcomes. To examine pairwise comparison between groups, we applied the Bonferroni post-hoc test with adjustment for multiple comparisons.

To study whether attendance to the exercise training program and adherence to the pre-determined intensity fixed (100% indicate that 100% of session were performed to intensity fixed) for each exercise group were associated with changes in physical fitness-related parameters (Figure S1), we conducted Pearson's correlation analyses. A level of significance of $p \leq 0.05$ was fixed. All statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS, v. 22.0, IBM SPSS Statistics, IBM Corporation). The graphical plots were created using the GraphPad Prism 5 (GraphPad Software).

3 | RESULTS

Figure 1 shows the participant flowchart. A total of 144 participants were randomly assigned to either the control group ($n = 54$; $n = 34$ women) or the MOD-EX group ($n = 46$; $n = 32$ women) and the VIG-EXgroup ($n = 44$; $n = 32$ women)). A total of ~27% of participants did not finish the intervention program (control group: $n = 18$ [~33%]; MOD-EX group: $n = 10$ [~22%]; VIG-EX: $n = 11$ [~25%]) for different reasons (e.g., change of address, medical reason, lack of time or familiar problems, among others).

Table 1 shows the descriptive characteristics of the participants who finished the intervention program.

A significant time*group interaction was observed in VO_{2max} in absolute terms and relative to body weight in both men and women (all $p < 0.04$, Figure 2). ANCOVA revealed significant differences between groups in VO_{2max} in absolute terms and relative to body weight in both men (Figure 2A,C, respectively) and women (Figure 2E,G, respectively) after the 24-week intervention study (all $p < 0.03$, Figure 2). VO_{2max} in absolute terms and relative to body weight increased in the MOD-EX (~8%) compared with the control group after the intervention study in men (all $p < 0.001$; Figure 2B,D). A significantly higher increment of VO_{2max} was noted in the MOD-EX group (~8%) compared with the VIG-EX (~6.5%) group (all $p < 0.05$). VO_{2max} in absolute terms increased in the MOD-EX and VIG-EX groups (~5.5%) compared with the control group after the intervention study in women (all $p < 0.001$, Figure 2F), while VO_{2max} relative to body weight was only enhanced in the VIG-EX group compared with the control group ($p = 0.014$, Figure 2H). No significant differences were detected in changes in VO_{2max} between both exercise groups in women (all $p > 0.6$).

Changes in muscular strength after the intervention compared with baseline among groups in men and women are shown in Figures 3 and 4, respectively. No significant differences in handgrip strength (Figure 3A,B), 1-RM leg press (Figure 3C,D), and 1-RM bench press (Figure 3E,F) were detected between groups in men (all $p > 0.05$). However, ANCOVA revealed significant differences between groups in 1-RM leg press after the 24-week intervention study in women ($p = 0.001$, Figure 4C), obtaining a significant increment of this outcome in the MOD-EX (~15.5%) and VIG-EX (~18%) groups compared with the control (~1%) group ($p = 0.004$ and $p = 0.002$, respectively; Figure 4D).

We showed a positive relationship of predetermined intensity fixed for each exercise group with changes in 1-RM leg press in the MOD-EX group in men ($p = 0.013$, Figure 5H). However, no association was noted between both the attendance to the exercise training program

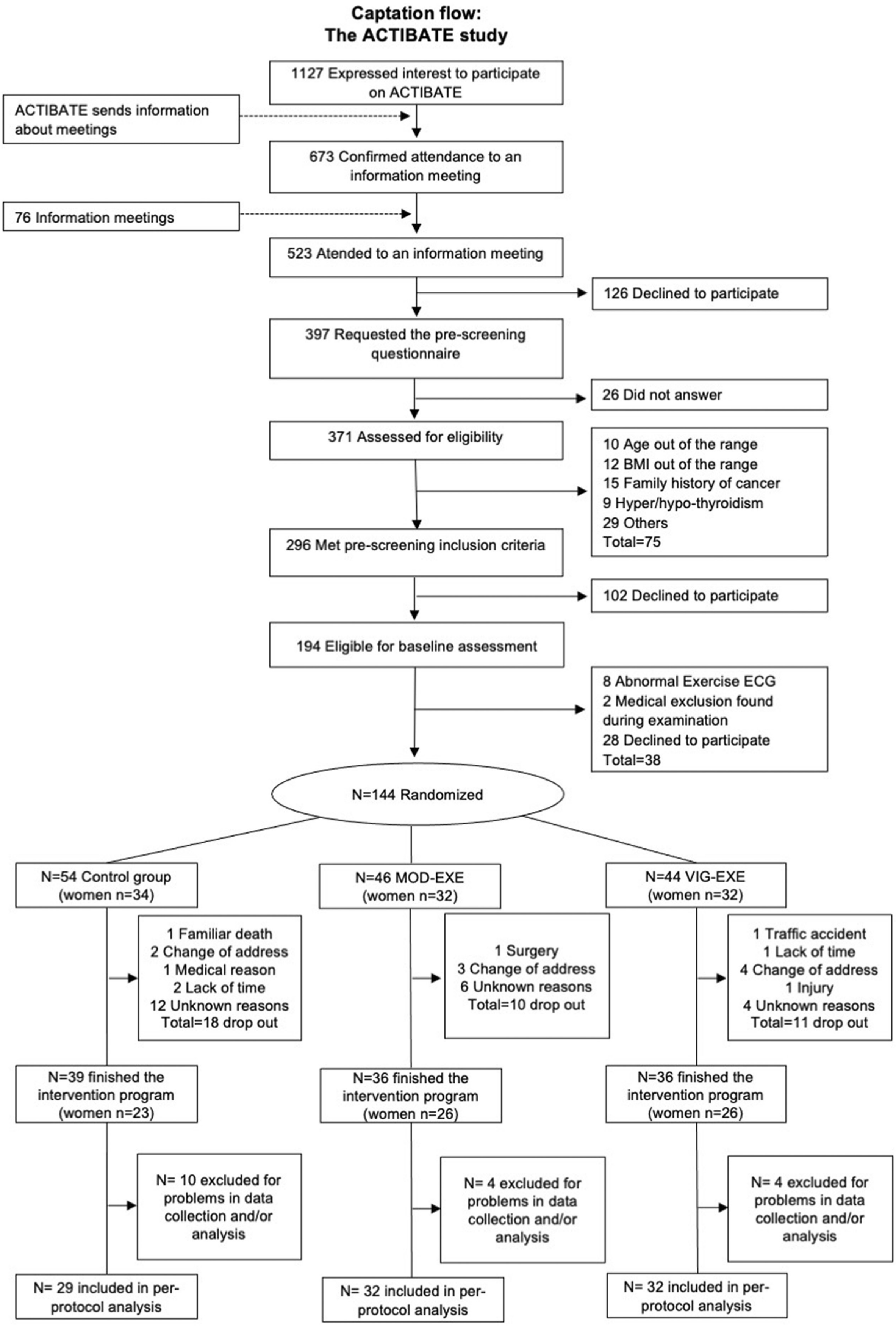


FIGURE 1 Flowchart diagram. BMI; body mass index, CDV; cardiovascular, ECG; electrocardiogram; MOD-EX, moderate intensity group; VIG-EX, vigorous intensity group.

TABLE 1 Baseline descriptive characteristics of the study participants that finished the intervention program.

	Women ($N=72$)			Men ($N=33$)		
	Control ($N=22$)	MOD-EX ($N=26$)	VIG-EX ($N=24$)	Control ($N=14$)	MOD-EX ($N=10$)	VIG-EX ($N=9$)
Age (years)	21.82 ± 2.07	22.01 ± 2.06	22.25 ± 2.33	21.46 ± 2.31	22.61 ± 2.05	22.63 ± 2.62
Body composition						
Body weight (kg)	60.45 ± 9.35	67.89 ± 12.58	65.55 ± 12.37	84.92 ± 18.18	77.31 ± 15.22	87.90 ± 19.34
Body height (cm)	162.98 ± 6.13	164.59 ± 6.94	165.14 ± 6.73	176.00 ± 6.69	174.11 ± 6.34	178.04 ± 6.89
Body mass index (kg/m^2)	22.78 ± 3.57	24.99 ± 4.05	23.97 ± 3.75	27.43 ± 5.87	25.47 ± 4.53	27.64 ± 5.42
Fat mass (kg)	22.14 ± 6.41	27.19 ± 8.33	24.60 ± 7.48	26.16 ± 11.57	22.39 ± 10.66	28.14 ± 11.39
Fat mass (%)	36.96 ± 6.03	40.16 ± 6.27	37.77 ± 5.28	30.37 ± 7.73	28.56 ± 7.64	31.61 ± 7.40
Lean mass (kg)	34.80 ± 4.08	37.12 ± 5.29	37.24 ± 5.27	54.01 ± 7.56	50.47 ± 5.61	54.73 ± 8.29
Physical fitness						
VO_{2max} (mL/min)	2454.7 ± 404.2	2654.0 ± 421.7	2499.7 ± 505.9	3687.27 ± 705.8	3394.87 ± 602.7	3844.54 ± 820.9
VO_{2max} (mL/kg$_{weight}$/min)	40.16 ± 6.73	39.58 ± 6.42	38.92 ± 7.56	44.57 ± 10.67	44.62 ± 6.67	46.26 ± 10.85
Time to exhaustion (s)	858.5 ± 127.4	888.7 ± 219.7	918.1 ± 135.8	974.5 ± 270.9	1100.7 ± 201.9	1050.0 ± 294.1
HRmax (beats/min)	194.48 ± 9.47	193.15 ± 11.00	194.38 ± 9.48	190.36 ± 11.44	194.07 ± 13.43	197.46 ± 13.95
Hand grip strength (kg)	26.18 ± 3.55	27.33 ± 4.17	27.49 ± 3.56	38.83 ± 6.36	42.80 ± 5.77	41.31 ± 8.24
1-RM leg press (kg)	155.84 ± 29.65	170.65 ± 42.39	166.82 ± 41.78	280.67 ± 61.71	276.49 ± 57.55	279.15 ± 35.81
1-RM bench press (kg)	20.78 ± 4.96	24.10 ± 4.70	23.93 ± 5.57	50.43 ± 10.06	50.94 ± 15.09	45.80 ± 8.86
Physical activity						
Sedentary time (min/day)	924.6 ± 49.3	941.0 ± 51.9	915.3 ± 41.4	937.7 ± 65.1	933.72 ± 42.0	938.03 ± 62.0
LPA (min/day)	22.1 ± 7.9	26.0 ± 16.3	22.8 ± 8.0	22.9 ± 9.3	27.89 ± 15.8	23.84 ± 15.8
MPA (min/day)	60.5 ± 26.1	59.7 ± 23.0	58.7 ± 21.6	54.8 ± 22.2	57.77 ± 18.0	49.13 ± 22.0
VPA (min/day)	1.1 ± 1.5	1.3 ± 1.8	1.8 ± 3.3	1.5 ± 2.0	1.67 ± 2.1	1.53 ± 2.0
MVPA (min/day)	61.6 ± 26.8	61.0 ± 23.5	60.5 ± 23.5	56.4 ± 22.9	59.43 ± 19.1	50.67 ± 22.5

Note: Data are shown as means ± standard deviation. p Value of analysis of variance analysis between groups.

Abbreviations: 1-RM, one-repetition maximum; HRmax, maximal heart rate; LPA, low physical activity; MOD-EX, moderate intensity group; MPA, moderate physical activity; MVPA, moderate-vigorous physical activity; VIG-EX, vigorous intensity group; VO_{2max}, maximal oxygen uptake; VPA, vigorous physical activity.

or the percentage of session performed with pre-determined intensity fixed for each exercise group and changes in the remaining physical fitness-related parameters (Figure 5A–G,I,J) after the intervention study in men (all $p \geq 0.05$).

We did not find a significant association of the attendance to the exercise training program and the percentage of session performed with predetermined intensity fixed for each exercise group with changes in physical fitness-related parameters after the intervention study in women (all $p \geq 0.05$; Figure 6A–J).

4 | DISCUSSION

The present study aimed to investigate the dose–response effects of a 24-week supervised CT program on cardiorespiratory fitness and muscular strength, with a special focused on the differences between men and women. The main findings indicate that the supervised exercise intervention would lead to different effects on cardiorespiratory fitness and muscular strength in males versus females, and that the predetermined intensity (moderate vs. vigorous) would have a relevant role in the physiological adaptations obtained. Specifically, while the MOD-EX group could result more appropriate in men, both MOD-EX and VIG-EX groups similarly improved cardiorespiratory fitness in women. Importantly, only significant increments of lower limb strength were noted in women independently of the pre-determined intensity (moderate vs. vigorous). These findings suggest that the exercise-induced fitness adaptations are different in men and women, and that sex should be taken into account in future exercise intervention studies.

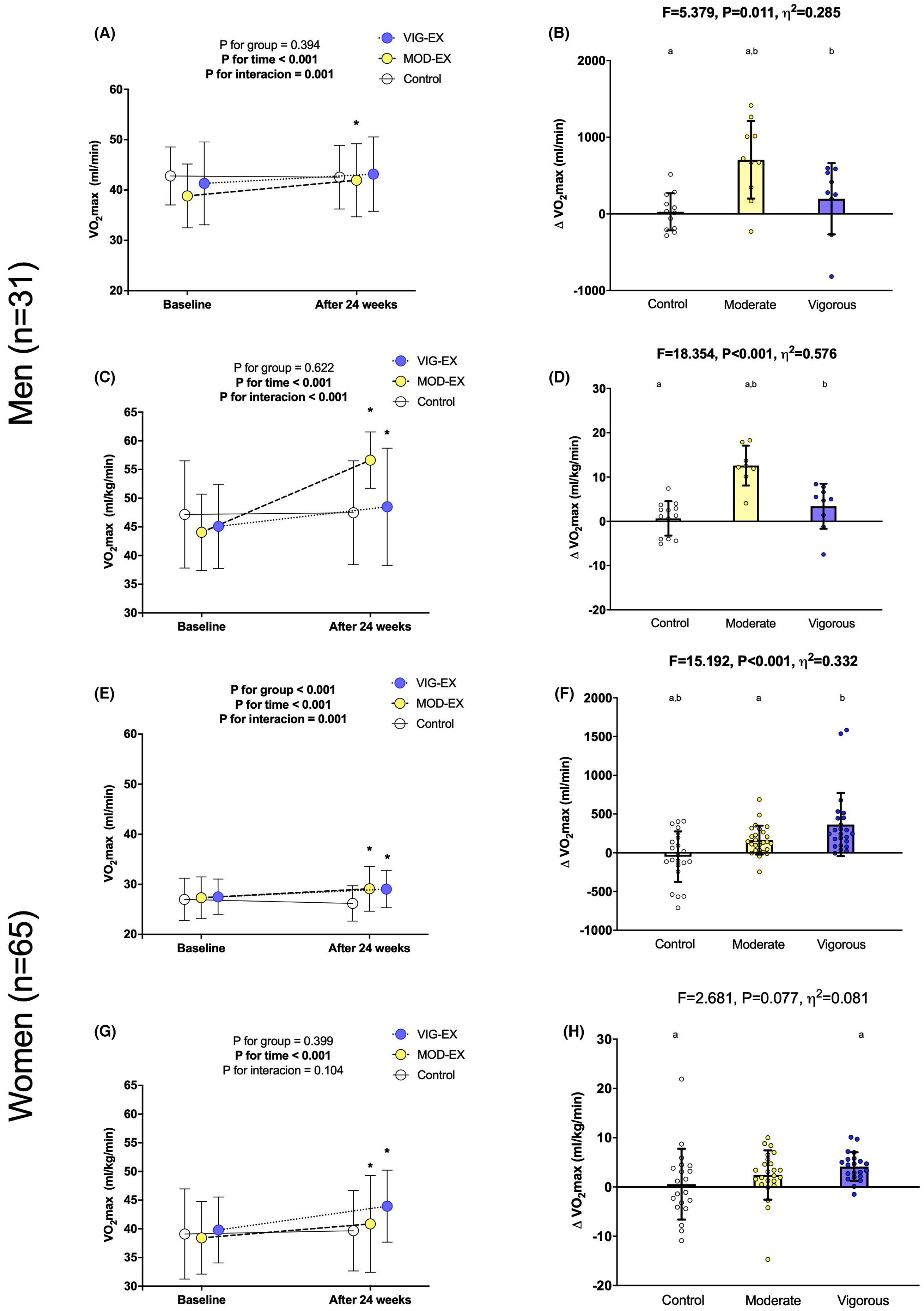

Men (n=31)
Women (n=65)
(A)
P for group = 0.394
P for time < 0.001
P for interacion = 0.001
VIG-EX
MOD-EX
Control
VO2max (ml/min)
Baseline
After 24 weeks
(B)
F=5.379, P=0.011, η2=0.285
Δ VO2max (ml/min)
Control
Moderate
Vigorous
(C)
P for group = 0.622
P for time < 0.001
P for interacion < 0.001
VO2max (ml/kg/min)
(D)
F=18.354, P<0.001, η2=0.576
Δ VO2max (ml/kg/min)
(E)
P for group < 0.001
P for time < 0.001
P for interacion = 0.001
(F)
F=15.192, P<0.001, η2=0.332
(G)
P for group = 0.399
P for time < 0.001
P for interacion = 0.104
(H)
F=2.681, P=0.077, η2=0.081

FIGURE 2 Changes in maximal oxygen uptake (VO_{2max}) for both men and women (Panels A, B, E and F), and in VO_{2max} relative to body weight in men and women (Panels C, D, G and H) at baseline, and after the 24-week CT intervention among the three groups. P value of analysis of covariance for the change in the outcome adjusting by baseline values, with post-hoc Bonferroni-corrected (Panels B, D, F, and H). The same letters indicate significant differences among groups. MOD-EX, moderate intensity group; VIG-EX, vigorous intensity group.

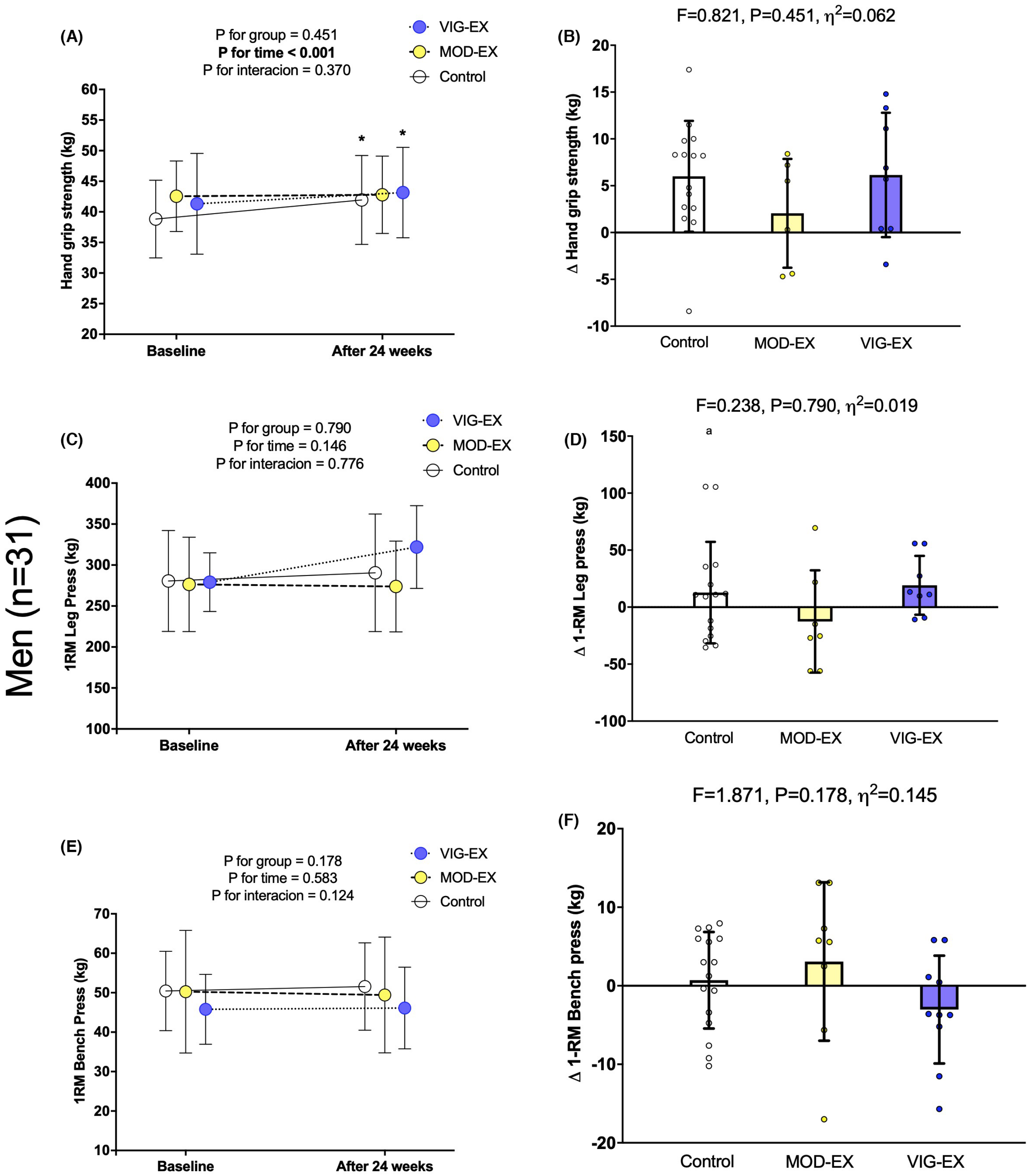


FIGURE 3 Changes in hand grip strength (Panels A, B), 1-RM leg press (Panels C, D) and 1-RM bench press (Panels E, F) for men at baseline, and after the 24-week CT intervention among the three groups. *p* Value of analysis of covariance for the change in the outcome adjusting by baseline values, with post-hoc Bonferroni-corrected (Panels B, D and F). The same letters indicate significant differences among groups. MOD-EX, moderate intensity group; VIG-EX, vigorous intensity group.

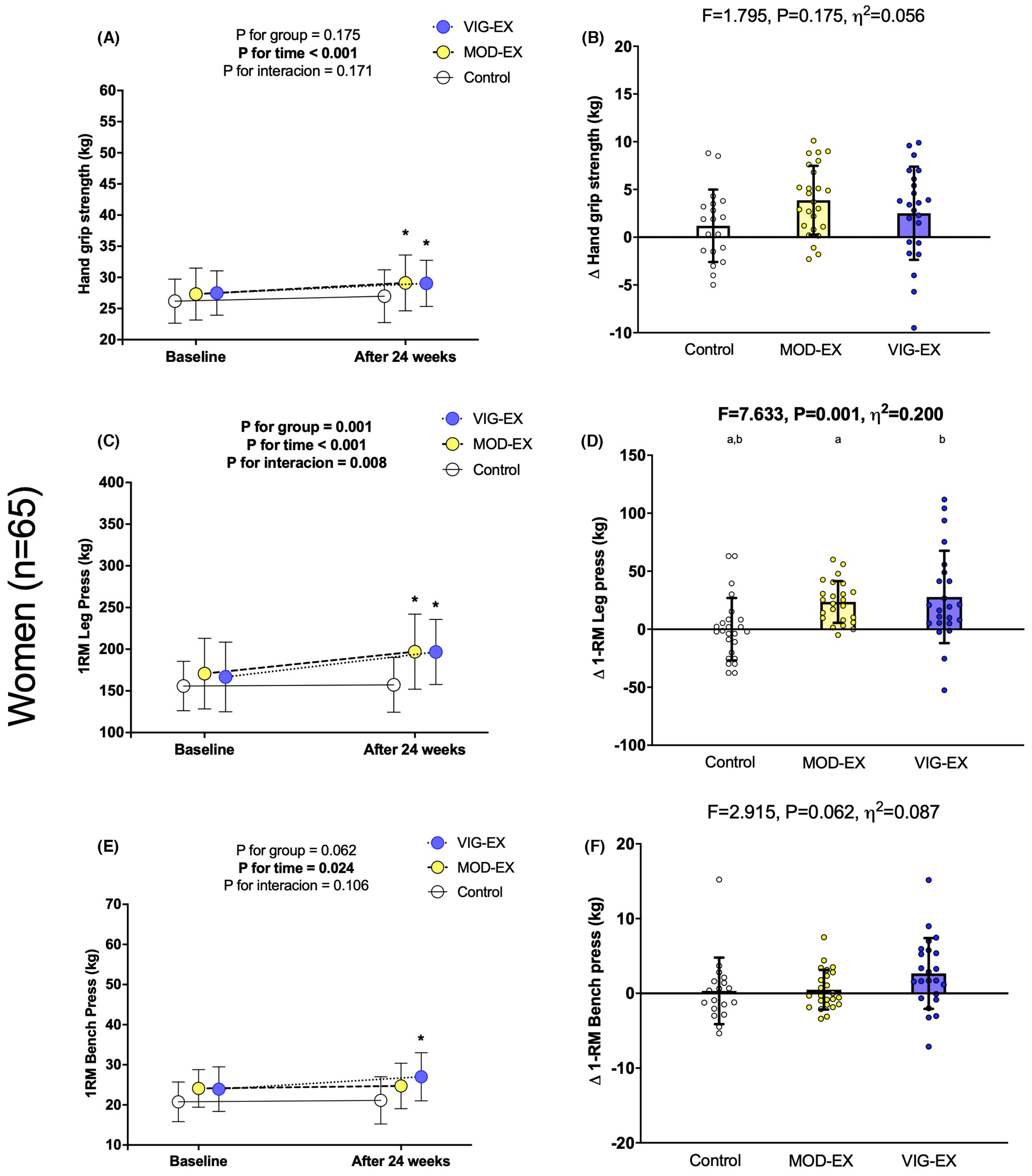
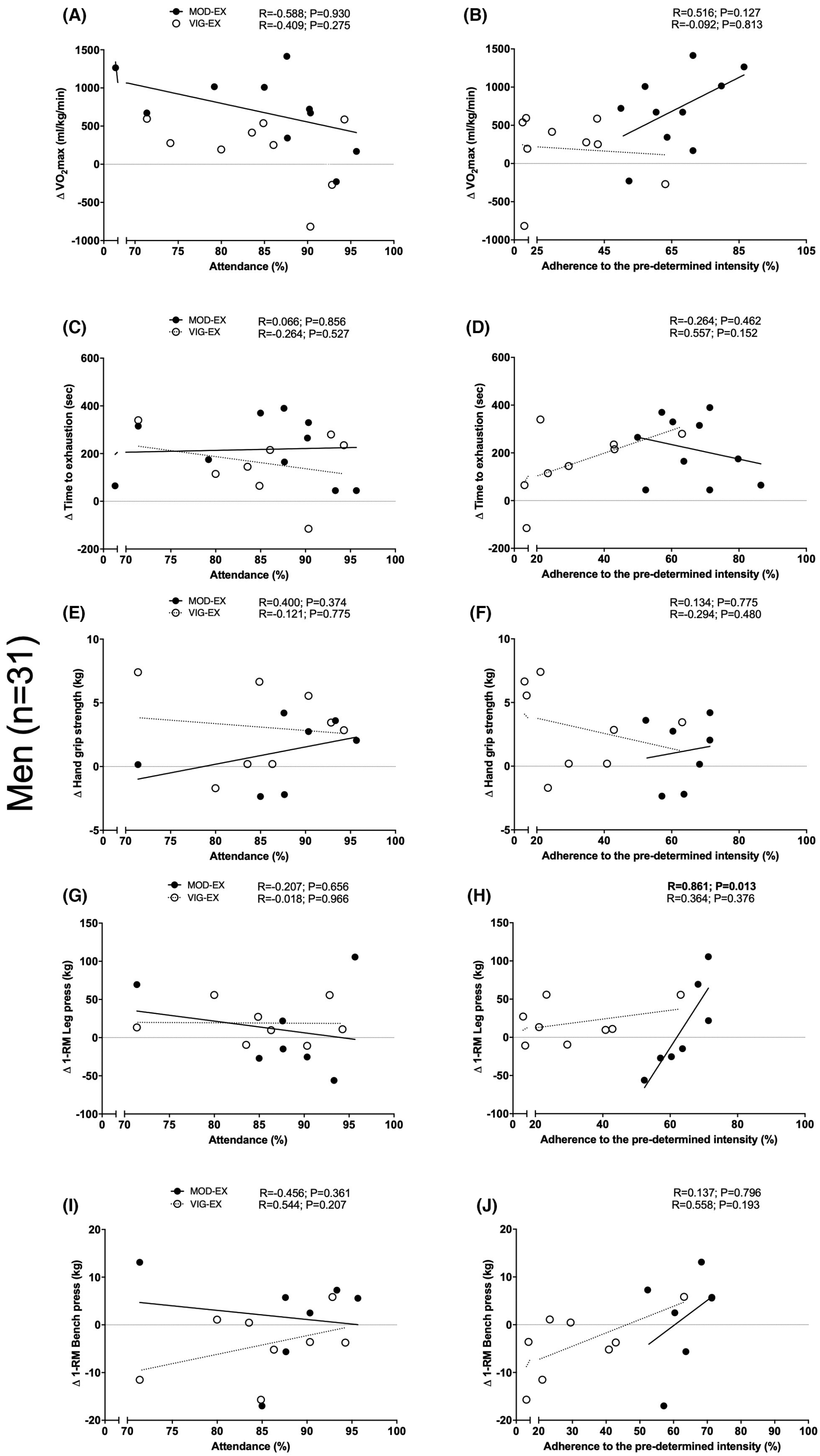


FIGURE 4 Changes in hand grip strength (Panels A, B), 1-RM leg press (Panels C, D) and 1-RM bench press (Panels E, F) for women at baseline, and after the 24-week CT intervention among the three groups. *p* Value of analysis of covariance for the change in the outcome adjusting by baseline values, with post-hoc Bonferroni-corrected (Panels B, D and F). The same letters indicate significant differences among groups. MOD-EX, moderate intensity group; VIG-EX, vigorous intensity group.

FIGURE 5 Association between attendance to the exercise training program and the percentage of session performed with pre-determined intensity fixed for each exercise group with changes in maximal oxygen uptake (VO_{2max}) (A, B), time to exhaustion (C, D), hand grip (E, F), 1-RM leg press (G, H), and 1-RM bench press (I, J) after the intervention study (i.e., 24 weeks—baseline) in men. MOD-EX, moderate intensity group; VIG-EX, vigorous intensity group.


Men (n=31)
(A)
MOD-EX
VIG-EX
R=-0.588; P=0.930
R=-0.409; P=0.275
Δ VO2max (ml/kg/min)
Attendance (%)
(B)
R=0.516; P=0.127
R=-0.092; P=0.813
Δ VO2max (ml/kg/min)
Adherence to the pre-determined intensity (%)
(C)
MOD-EX
VIG-EX
R=0.066; P=0.856
R=-0.264; P=0.527
Δ Time to exhaustion (sec)
Attendance (%)
(D)
R=-0.264; P=0.462
R=0.557; P=0.152
Δ Time to exhaustion (sec)
Adherence to the pre-determined intensity (%)
(E)
MOD-EX
VIG-EX
R=0.400; P=0.374
R=-0.121; P=0.775
Δ Hand grip strength (kg)
Attendance (%)
(F)
R=0.134; P=0.775
R=-0.294; P=0.480
Δ Hand grip strength (kg)
Adherence to the pre-determined intensity (%)
(G)
MOD-EX
VIG-EX
R=-0.207; P=0.656
R=-0.018; P=0.966
Δ 1-RM Leg press (kg)
Attendance (%)
(H)
R=0.861; P=0.013
R=0.364; P=0.376
Δ 1-RM Leg press (kg)
Adherence to the pre-determined intensity (%)
(I)
MOD-EX
VIG-EX
R=-0.456; P=0.361
R=0.544; P=0.207
Δ 1-RM Bench press (kg)
Attendance (%)
(J)
R=0.137; P=0.796
R=0.558; P=0.193
Δ 1-RM Bench press (kg)
Adherence to the pre-determined intensity (%)

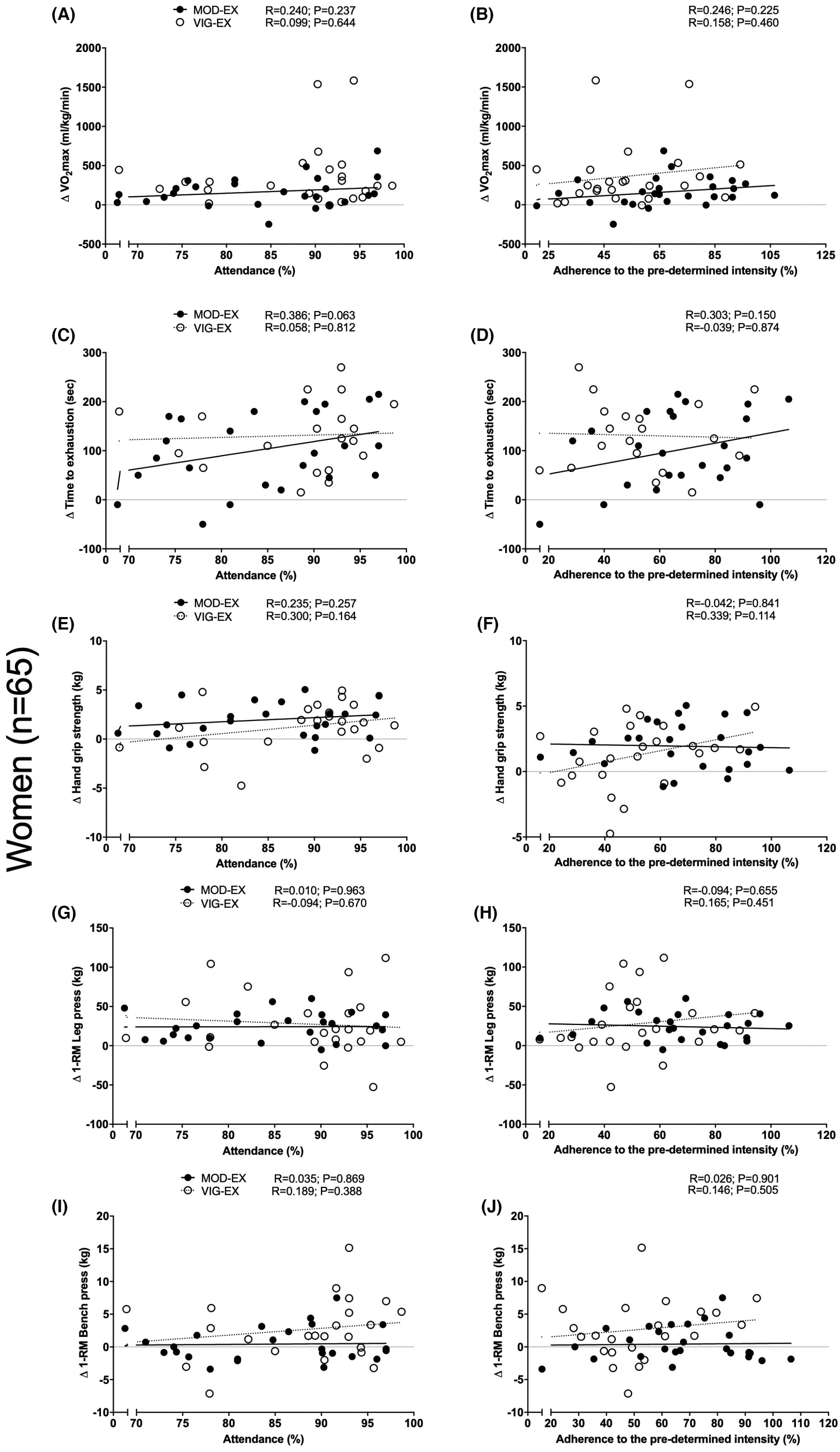

Women (n=65)
(A)
MOD-EX R=0.240; P=0.237
VIG-EX R=0.099; P=0.644
Δ VO2max (ml/kg/min)
Attendance (%)
(B)
R=0.246; P=0.225
R=0.158; P=0.460
Adherence to the pre-determined intensity (%)
(C)
MOD-EX R=0.386; P=0.063
VIG-EX R=0.058; P=0.812
Δ Time to exhaustion (sec)
(D)
R=0.303; P=0.150
R=-0.039; P=0.874
(E)
MOD-EX R=0.235; P=0.257
VIG-EX R=0.300; P=0.164
Δ Hand grip strength (kg)
(F)
R=-0.042; P=0.841
R=0.339; P=0.114
(G)
MOD-EX R=0.010; P=0.963
VIG-EX R=-0.094; P=0.670
Δ 1-RM Leg press (kg)
(H)
R=-0.094; P=0.655
R=0.165; P=0.451
(I)
MOD-EX R=0.035; P=0.869
VIG-EX R=0.189; P=0.388
Δ 1-RM Bench press (kg)
(J)
R=0.026; P=0.901
R=0.146; P=0.505

FIGURE 6 Association between attendance to the exercise training program and the percentage of session performed with predetermined intensity fixed for each exercise group with changes in maximal oxygen uptake (VO_{2max}) (A, B), time to exhaustion (C, D), hand grip (E, F), 1-RM leg press (G, H), and 1-RM bench press (I, J) after the intervention study (i.e., 24 weeks—baseline) in women. MOD-EX, moderate intensity group; VIG-EX, vigorous intensity group.

4.1 | 24-week CT supervised intervention effects on cardiorespiratory fitness: Role of sex

It is well-known the robust and inverse relationship between cardiorespiratory fitness and risk of cardiovascular disease and all-cause mortality.[6] CT has been positioned as an effective training method to increase VO_{2max} (~6.3%), independently of the exercise intensity (Ramos-Campos, 2021). Thus, the significant improvements in absolute VO_{2max} obtained after our 24-week CT intervention, concur with similar previous interventions conducted in young individuals[18,32] and in middle-aged adults.[14] These notorious enhancements could be explained not only by peripheral adaptations (e.g., upregulation of angiogenesis), but also by the optimization of central physiological mechanisms (e.g., maximal stroke volume or cardiac output), both contributing to optimize oxygen delivery and utilization. Moreover, previous studies that performed shorter CT interventions found similar improvements.[17,18] Concretely, they reported increments of ~5.5%[17] and ~10% in VO_2 max, after only 24 training sessions (i.e., 8 weeks, three times per week) of vigorous and/or moderate CT. Therefore, it seems that short-term CT programs could be sufficient to improve cardiorespiratory fitness in young adults.

Paradoxically, our results suggest that, while CT at moderate intensity was more effective to increase absolute VO_{2max} in males (~8% in MOD-EX vs. ~6.5% VIG-EX), both equally improved relative VO_{2max} in females (~5.5%). Sex-dependent anthropometric and physiological differences may explain these controversial findings. Specifically, women exhibit increased fatigue resistance during vigorous bouts of exercise[33] and present a faster ATP recovery compared to men.[34] Furthermore, women usually show a marked tendency for aerobic metabolism during exercise, a factor that facilitates adherence to the predetermined intensity when it is vigorous.[33] Finally, previous evidence shows that the aerobic contribution during vigorous intensity is ~25% higher in females than males.[35]

4.2 | 24-week CT supervised intervention effects on muscular strength: Role of sex

Muscular strength adaptations in response to CT interventions could to be different in men and in women. In females, results of the present study showed significant improvements of lower limb maximal strength in both MOD-EX (~15.5%) and VIG-EX (~17%) groups (with no differences between them) compared with the control group. These findings concur with those obtained by previous studies which programmed CT interventions in young women.[32,36] Silva et al. showed a significant increment of upper- (~17%) and lower-body (40%) 1RM muscular strength after a 11-week intervention combining resistance and sprint interval training in the same session. In addition, an 8-week CT intervention applying an intensity of 95% of the ventilatory threshold 2 was effective to improve lower limb (~38%) strength in college female participants.[32] Interestingly, the present study achieved improvements in lower limbs in response to both moderate and vigorous intensities with a similar magnitude than the above-mentioned studies which set their intervention at high-intensities. This fact suggests that, in women, long-term CT intervention could be needed if lower intensities are programmed.

Previous investigations have demonstrated that a well-designed CT improves lower body limbs[17,18] and upper limbs strength[18] in active young males. Even a short-time CT intervention (i.e., 8 weeks) at a moderate to vigorous intensity resulted in significant improvements of maximal lower body limbs strength.[17] In contrast to our initial hypothesis, we showed no significant differences in muscular strength between the MOD-EX and the VIG-EX groups compared with the control group in men. These unexpected results could be partially attributed to the fact that the participants of our study allocated in the control group received verbal information regarding physical activity recommendations provided by the WHO.[13] Of note is that ~30% of them reported having performed regular physical exercise during the intervention study. Considering that young individuals (especially men) are characterized by increased muscle anabolic signaling and myofibrillar protein synthesis, it is plausible that the lack of differences among groups could be explained by this point.

It is well-known that a key aspect for improving physical fitness in response to an exercise intervention is the attendance to the training session and adherence to the predetermined intensity fixed.[37] In fact, among factors that are associated with a proper adherence are the intensity-duration of the prescribed exercise or the overall duration of the intervention.[38] In most of the clinical outcomes, 80% has been used as the universal threshold for a correct adherence to the exercise program.[39] However, as in general adherence to exercise programs usually decreases to ~60%,[40] and due to the long-term length of the present intervention (i.e., 24 weeks), the participants with >70% of attendance were included in the final analysis. Nevertheless, we observed a lack of association between attendance to the exercise training program and changes in physical fitness-related parameters after the intervention study. Although it has been documented that moderate exercise intensity would result in greater maintenance and adherence to exercise,[40] our findings do not support this notion as physical fitness changes were independent of the CT intensities. Setting vigorous intensities could be a limitation for exercise' adherence,[41] yet, sex does not seem to be a moderator in the present study as both males and females did not show significant differences in their patterns. In this regard, CT could be easily implemented as a new lifestyle habit in this population—independently of the intensity programmed.

The main strength of the present study is the analysis of different intensities of concurrent training which could allow the individualized design of exercise programs to improve physical condition depending on sex. However, some limitations should be taken into account. The results should be considered exploratory and interpreted cautiously, as the study was not specifically powered for sex-separate analysis and the sample size per group, especially in the analyses on men, might have been relatively small. It should be also highlighted that the sex distribution was not balanced in this sample, with roughly half men than women being included in the main analyses. For this reason, a posteriori power analysis was calculated. Caution should be paid on the number of comparisons conducted, and the potential propagation of Type I error rate. Besides, the relatively high number of participants allocated in the control group that performed regular physical exercise during the intervention program makes the comparison between groups difficult to interpret. Finally, we only recruited non-trained young adults aged between 18 and 25 years, thus we cannot extend these results to other populations.

In conclusion, the present study shows that a 24-week supervised CT intervention was effective at improving cardiorespiratory fitness and lower body limbs muscular strength in young women—independently of the predetermined exercise intensity—while in men, only the exercise at moderate intensity improved cardiorespiratory fitness.

5 | PERSPECTIVE

Concurrent training has been postulated as an appropriate time-efficient strategy to improve physical fitness, yet whether the exercise-induced adaptations are similar in men and women has been less studied. In addition, whether higher exercise intensities differently influence on physical fitness depending on the individuals' sex has been showed as an interest aspect to investigate. This study shows that a 24-week supervised concurrent exercise intervention led to improvements on physical fitness in young adults. While in young women, cardiorespiratory fitness and lower body limbs strength were improved, independently of the exercise training intensity, in young men, moderate intensity was sufficient to improve cardiorespiratory fitness. To analyze the sex-specific effects of a concurrent exercise intervention at different intensities on physical fitness could be of great interest in the fitness industry, since they may help to optimize new, personalized and challenging workouts for both sexes, thus increasing physical fitness and health purposes, enjoyment, and interest.

AUTHOR CONTRIBUTIONS

Alba Camacho-Cardenosa, Francisco J. Amaro-Gahete, and Jonatan R. Ruiz drafted the manuscript, and Francisco J. Amaro-Gahete and Jonatan R. Ruiz conducted the statistical analysis. Alba Camacho-Cardenosa, Francisco J. Amaro-Gahete, Francisco B. Ortega, and Jonatan R. Ruiz participated in the design of the study, and Francisco J. Amaro-Gahete, Borja Martinez-Tellez, Juan M. A. Alcantara, and Jonatan R. Ruiz contributed to data collection and data analysis. All authors contributed to the manuscript writing and discussion. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Alba Camacho-Cardenosa https://orcid.org/0000-0002-7682-8336
Francisco J. Amaro-Gahete https://orcid.org/0000-0002-7207-9016
Borja Martinez-Tellez https://orcid.org/0000-0001-8783-1859
Juan M. A. Alcantara https://orcid.org/0000-0002-8842-374X
Francisco B. Ortega https://orcid.org/0000-0003-2001-1121
Jonatan R. Ruiz https://orcid.org/0000-0002-7548-7138

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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