

1 **Hybrid Neuromuscular Training Promotes Musculoskeletal Adaptations in**
2 **Inactive Overweight and Obese Women: A Training-Detraining**
3 **Randomized Controlled Trial**

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10

11 **Abstract**

12 This study investigated the effects of a 10-month high-intensity interval-type neuromuscular training
13 program on musculoskeletal fitness in overweight and obese women. Forty-nine inactive females
14 (36.4±4.4 yrs) were randomly assigned to either a control (N=21), a training (N=14, 10 months) or a
15 training-detraining group (N=14, 5 months training followed by 5 months detraining). Training used
16 progressive loaded fundamental movement patterns with prescribed work-to-rest intervals (1:2, 1:1, 2:1)
17 in a circuit fashion (2-3 rounds). Muscular strength and endurance, flexibility, passive range of motion
18 (PRoM), static balance, functional movement screen (FMS) and bone mass density (BMD) and content
19 (BMC) were measured at pre-, mid-, and post-intervention. Ten months of training induced greater
20 changes than the controls in (i) BMD (+1.9%, $p<0.001$) and BMC (+1.5%, $p=0.023$) ii) muscular
21 strength (25%-53%, $p=0.001-0.005$); iii) muscular endurance (103%-195%, $p<0.001$); and iv) mobility
22 (flexibility: 40%, $p<0.001$; PRoM [24%-53%, $p=0.001-0.05$]; balance: 175%, $p=0.058$; FMS: +58%,
23 $p<0.001$). The response rate to training was exceptionally high (86-100%). Five months of detraining
24 reduced but not abolished training-induced adaptations. These results suggest that a hybrid-type exercise
25 approach integrating endurance-based bodyweight drills with resistance-based alternative modes into a
26 real-world gym setting may promote musculoskeletal fitness in overweight or obese women.

27 **Keywords:** intermittent exercise; females; muscular strength; mobility; functional movement patterns,
28 bone health.

29

30 **Word count:** 4,361

31 **Introduction**

32 Obesity is a multifactorial chronic condition affecting one in three adults worldwide (29).
33 Individuals with obesity demonstrate low cardiorespiratory fitness, high metabolic risk and
34 physical limitations (11,32). This population demonstrates biomechanical deficits in activities
35 of daily living (ADL) and reduced passive range of motion (PRoM) in several joints (19)
36 compared to lean individuals. Such kinetic limitations due to restricted musculoskeletal fitness
37 and mobility levels predispose obese individuals to injuries and lead to impaired functionality
38 and reduced quality of life (42). Overweight or obese adults also exhibit a 15% and 48%,
39 respectively, higher risk of sustaining an injury (35) and these rates are even higher for industry
40 workers (17).

41 Musculoskeletal fitness is characterised by lean body mass (LBM), muscular strength and
42 endurance, balance and mobility, which contribute to physical performance, resting metabolic
43 rate improvement, osteoporosis prevention and body functionality in ADL (20). Low
44 musculoskeletal fitness levels may predispose obese adults to hip, foot, ankle, knee and
45 shoulder injuries and may cause soft tissue (cartilage, tendons and fascia) damage (42).
46 Although, the etiology is largely unclear, the overloading of the locomotor apparatus combined
47 with the poor musculoskeletal strength and mobility produce impaired mechanics during
48 movement that increases the stress within the soft tissue and bones (42). Obesity may also be
49 related to a lower bone mineral density (BMD) and content (BMC) (36). Although **overweight**
50 **and obese** adults tend to have higher absolute BMC values than adults of healthy weight, after
51 adjusting for total body mass, their BMC is markedly lower than that of their controls (36). In
52 other words, the elevated BMD usually measured in adults with obesity may not be adequate
53 to offset the greater forces developed during low- or high-velocity movements.

54 Regular exercise is an efficient tool for improving **physical fitness, health and body**
55 **composition** in this population (1). Current exercise guidelines include progressive protocols of
56 continuous endurance training (CET), resistance training (RT), or combined CET and RT

57 training (CT) to induce cardiorespiratory, neuromuscular and metabolic adaptations (1).
58 Structured RT is pivotal for preventing sarcopenia and osteoporosis in sedentary,
59 premenopausal women with obesity through improvements in LBM and physical performance
60 (21,40). High-intensity interval training (HIIT) is one of the most popular exercise modes (3)
61 requiring less exercise volume compared to CET, RT, or CT and demonstrating high
62 compliance rates when conducted under supervision in untrained individuals (34). HIIT
63 includes repeated short-to-long bouts performed at an intensity that provokes a heart rate (HR)
64 $\geq 80\%$ of maximal heart rate (MHR) (39). The present, injury-free, hybrid-type exercise protocol
65 integrates progressive HIIT and functional resistance accessory training into a circuit training
66 format that has been shown to reduce body fat, increase LBM, RMR, endurance, exercise
67 behavioural regulation and vitality with exceptional adherence rates in previously inactive
68 women with obesity (4,6). Such an exercise approach incorporates endurance-based
69 bodyweight drills and resistance-based alternative modalities (18) performed in a circuit,
70 interval format and at moderate-to-high intensity adopting some of the principal characteristics
71 of multimodal integrative neuromuscular training (44).

72 Although there is evidence that overweight or obese adults need comprehensive exercise
73 strategies not only to reduce body mass and fat (1) but also to improve functional limitations
74 while avoiding physical training-related injuries (37), there is a paucity of longitudinal studies
75 to determine the efficacy of such a HIIT-type neuromuscular exercise approach on
76 musculoskeletal fitness, mobility and bone health. Additionally, it is important to investigate
77 potential changes in such physiological parameters, which result from the cessation of exercise,
78 since exercise training is considered a fundamental component of every lifestyle intervention
79 for this population. It has been observed an unfavorable effect of detraining on neuromuscular
80 performance that was mainly influenced by the duration of training cessation, age, and training
81 status (45). Characteristically, when an 8-month multicomponent exercise program performed

82 by older overweight women was interrupted for only three months, musculoskeletal
83 performance gains induced by previous training were abolished (49).

84 To our knowledge, there is no data concerning the effects of training cessation on
85 musculoskeletal fitness parameters in sedentary overweight and obese individuals. We
86 hypothesized that the training would induce favorable changes in musculoskeletal fitness.
87 Therefore, this study aimed to determine the effects of the a HIIT-type, neuromuscular training
88 protocol on (i) muscular strength and muscular endurance, (ii) joints' range of motion, (iii)
89 balance, (iv) functional movement patterns, and (v) bone health of previously inactive,
90 premenopausal Caucasian women with obesity.

91

92 **Materials and Methods**

93

94 *Study design*

95 This study is a part of a larger longitudinal research project whose purpose, methodology and
96 primary outcomes are reported elsewhere (6). In this investigation, data upon musculoskeletal
97 fitness are presented. This study was a randomised controlled trial based on a three-group,
98 repeated-measures design in accordance with the Consolidated Standards of Reporting Trial
99 (CONSORT) guidelines (Figure 1) and it was registered at clinicaltrials.gov as NCT03134781.
100 Initially, 102 participants were assessed for eligibility, 66 were recruited and allocated to three
101 groups, and 49 completed the trial as required (see Figure supplemental Digital Content 1).

102 Participants (36.4 ± 4.4 years) were randomly assigned to a training (TR, $n=14$), a training-
103 detraining group (TRD, $n=14$) or a control (C, $n=21$) group. Following a 4-week adaptive and
104 familiarization period **as previously articulated** (6), TR performed the 10-month exercise
105 training protocol whereas TRD performed the same protocol for 5 months and then entered a
106 5-month detraining period. Abstinence from exercise in the detraining group was verified using
107 accelerometry (GT3X-BT, ActiGraph, FL, USA). Accelerometry data were used in the analysis,

108 only if participants had ≥ 4 days and ≥ 10 wear hours/day. Four vector magnitude data were used
109 to calculate daily activity and sedentary time. Data were expressed as steps/day and time in
110 sedentary, light, moderate, vigorous and moderate-to-vigorous physical activity as described
111 (6). Assessments of musculoskeletal fitness were performed at pre-, mid-, and post-training
112 (Figure 1). All assessment procedures were completed with the same order (bone health,
113 flexibility, static balance, functional movement patterns, maximal strength, muscle endurance)
114 at pre-, mid- and post-training.

115

116

FIGURE 1 ABOUT HERE

117

118 *Participants*

119 Participants were medically cleared for strenuous exercise, were non-smokers and of low
120 regular PA or structured exercise for ≥ 6 months before the study. None of them were on
121 medication, diet or nutritional supplementation. Participants were excluded if they missed
122 $\geq 20\%$ of total exercise sessions, changed their eating habits and modified their PA levels during
123 the intervention. Participants during detraining need to have comparable PA levels with pre-
124 training. Participants were informed about all risks, discomforts and benefits associated with
125 the study and provided a written consent. This investigation was carried out in accordance with
126 the guidelines contained in the 2013 Declaration of Helsinki and was approved by the
127 Institutional Ethics Committee. Participants' characteristics are shown in Table 1.

128

129

TABLE 1 ABOUT HERE

130

131 *Training*

132 Three small-group (5-10 participants per session), supervised training sessions per week that
133 used asynchronous music in the background were performed on non-consecutive days for TR

134 (10 months) and TRD (5 months) as previously reported (6). This hybrid-type protocol was
135 organized in four progressive training phases (i.e., phase 1: weeks 1-7, phase 2: weeks 8-14,
136 phase 3: weeks 15-20 and phase 4: 21-40) (Figure 1). The mean weekly exercise volume was
137 ~100 min, net exercise time was 6.5-24.0 min per session and total duration per session was
138 23-41 min (6). Exercises (see Table, Supplemental Digital Content 2) adapted basic movement
139 patterns (squat, hinge, lunge, push, pull, carry, rotation, plank) utilizing portable modalities
140 (suspension belts, balance balls, kettlebells, medicine balls, battle ropes, stability balls, speed
141 ladders, foam rollers, elastic bands) and bodyweight as resistance. Exercises (~10-12 per
142 session) were organized in a circuit format and performed in all planes of motion simulating
143 ADLs. The work-to-rest ratio was varied (1:2, 1:1, 2:1) using an interval duration of 20-40 sec
144 to provide progression (see Table, Supplemental Digital Content 2) (6). Verbal encouragement
145 was provided. Participants were instructed to execute as many repetitions as possible with the
146 correct form and with a controlled, moderate rhythm. A 10-min warm-up and a 5-min cool
147 down period was applied in all sessions (6). HR was monitored and recorded using telemetry
148 (Polar Team Solution, Polar Electro-Oy, Kempele, Finland) aiming to maintain an intensity
149 $\geq 75\%$ of MHR throughout each session. Rating (6-20) of perceived exertion (RPE) was
150 recorded at the end of each round in all sessions using the 6-20 Borg scale.

151

152 *Measurements*

153

154 *Bone Health*

155 Whole-body BMC and BMD were performed using a dual energy X-ray absorptiometry (DXA)
156 scanner (GE Healthcare, Lunar DPX-NT) in the morning by the same experienced radiologist
157 according to standard procedures (41). Briefly, participants were placed in a supine position
158 with their body aligned along the central horizontal axis, their arms parallel to their body
159 (without touching it), the forearms pronated, hands flat, legs fully extended, and feet secured

160 using a velcro strap to prevent foot movement during the scan. The instrument was calibrated
161 daily using a calibration epoxy resin phantom. All analyses were performed using the 12.2 GE
162 enCORE software package.

163

164 *Flexibility, Static Balance and Mobility*

165 A 3-min cycling warm-up preceded mobility testing (three consecutive measurements).
166 Flexibility of lower back and hamstrings was measured under standardized conditions using the
167 modified sit-and-reach test (2). Goniometry (Lafayette 01135, Lafayette Instrument Inc.,
168 Lafayette, IN, USA) was applied to assess the PRoM (in degrees) of ankle dorsiflexion, knee
169 extension, hip extension, shoulder extension, and glenohumeral internal rotation (31). Both
170 extremities were examined and the median of their measurements was reported as the value in
171 goniometry.

172 Static balance was assessed using the modified Romberg test. Participants were asked to
173 stand without shoes on a firm surface, with eyes closed and arms crossed on the chest and the
174 dominant foot placed directly in front of the non-dominant foot. The time to failure was
175 measured manually by stopwatch in sec (30).

176 The Functional Movement Screening (FMS) with an ICC of >0.8 was used to evaluate
177 functional mobility, postural stability and movement behavior in different settings (23). Two
178 examiners (with an intra-rater reliability of 88.6%) performed this assessment. The FMS has
179 been reported as a simple, quick, non-invasive and suitable movement-based assessment tool
180 for middle-aged, **overweight or obese** aiming to evaluate their functional capacity levels (23).
181 In brief, the FMS assesses seven fundamental movement tasks (deep squat, hurdle step, in-line
182 lunge, active straight-leg raise, trunk stability push-up, rotary stability, shoulder mobility). Each
183 movement task was scored from 0 to 3 points (0=pain with pattern regardless of quality,
184 1=unable to perform pattern, 2=able to perform pattern with compensation/imperfection,

185 3=able to perform pattern as directed) and their sum provided the total score ranging from 0 to
186 21 points (46).

187

188 *Muscular Strength and Endurance*

189 Maximal isotonic strength (one repetition maximal, 1RM) was assessed using standard
190 procedures for novice and untrained individuals following familiarization as previously
191 described (2) with an intra-class correlation coefficient (ICC) for test-retest trials of 0.88. Two
192 upper-body (vertical chest press, supinated closed-grip lat pulldown) and two lower-body
193 (seated leg extension, lying leg curl) exercises performed on traditional strength training
194 equipment (Panatta Sport, Apiro, Italy) were selected. Muscular endurance was assessed using
195 timed tests for the abdominal (partial curl-up), upper-body (modified kneeling push-up) and
196 lower-body (modified chair squat) musculature (2). All tests required the participants to
197 perform as many repetitions as possible within 60 sec using standard procedures and a 5-min
198 rest was provided between tests (2).

199

200 *Statistical Analyses*

201 A preliminary power analysis (effect size >0.55 , probability error of 0.05, two-tailed alpha
202 level, power of 0.9) using the G*Power 3.0.10 program based on the study design suggested
203 that a sample of 36-40 participants was necessary to identify statistically meaningful trial
204 effects. For all dependent variables, differences (for both “between” and “within” groups) of
205 means (MD) and confidence intervals (CI) were calculated based on mixed models. Cohen’s *d*
206 criteria were used to interpret the magnitude of MD as very small, small, medium, large, very
207 large and huge for values 0.01, 0.20, 0.50, 0.80, 1.20 and 2.0, respectively. No assumptions
208 were made for covariance matrices (unstructured) since repetitions were not that many to
209 significantly reduce the degrees of freedom. All estimations were corrected based on the
210 Bonferroni criterion for multiple comparisons. Results are presented as relative difference in

211 time ($\Delta\%$). Since the variability of the change score in the intervention groups was greater than
212 that in C, the response rate was analysed using the number of differential responders relative to
213 the ratio of variance in TR and C groups providing multiple differential responder groups (10).
214 Statistical significance was set at $p < 0.05$. Data were analysed using the SPSS 22.0 software
215 (IBM Corp., Armonk, NY, USA).

216

217 **Results**

218 No injuries or other adverse effects occurred during the trial. Adherence rates for TR (10-month
219 intervention) and TRD (5-month intervention) were 93.5% and 82.6%, respectively, and a 4%
220 dropout rate was reported. Results are described in brackets as $\Delta\%/95\% \text{ CI}/d/p$ levels.

221

222 *Bone mineral density and bone mineral content*

223 Changes in BMD and BMC are shown in Table 2. No changes were observed between TR and
224 TRD. TR only improved BMD following training (Table 2) ($+1.9\%/0.010\text{--}0.035/2.61/p < 0.001$)
225 and BMC ($+1.5\%/0.04\text{--}0.076/2.72/p = 0.023$) and its response rate to whole-body BMD was
226 100% (Figure 4).

227

228 *Flexibility, Static Balance and Mobility*

229 Changes in flexibility and passive range of motion are shown in Table 2. At mid-training, TR
230 and TRD demonstrated greater flexibility changes than C (TR vs. C: $+38\%/3.939\text{--}$
231 $16.490/1.66/p = 0.001$; TRD vs. C: $+34\%/3.010\text{--}15.561/1.31/p = 0.002$). At post-training, TR and
232 TRD elicited more favorable changes in flexibility than C (TR vs. C: $+40\%/4.465\text{--}$
233 $17.130/1.83/p < 0.001$; TRD vs. C: $+26\%/0.572\text{--}13.238/1.02/p = 0.028$). No significant
234 differences were observed between TR and TRD. In TR, the response rate to flexibility was
235 100% (Figure 4).

236 Changes in PRoM are shown in Table 2. At mid training, TR and TRD showed significant
237 differences than C in hip extension (TR vs. C: +43%/0.678–9.607/1.08/ $p=0.019$; TRD vs. C:
238 +41%/0.393–9.322/1.08/ $p=0.029$), glenohumeral internal rotation (TR vs. C: +24%/5.676–
239 22.991/1.45/ $p<0.001$; TRD vs. C: +17%/1.747–19.062/1.04/ $p=0.014$). No changes were noted
240 between TR and TRD. At post-training, TR demonstrated a trend for a rise in PRoM compared
241 to C in ankle dorsiflexion (+44%/-0.543–10.924/0.86/ $p=0.088$) and shoulder extension
242 (+24%/0.178–15.940/0.93/ $p=0.057$). TR elicited greater PRoM changes than C and TRD in
243 glenohumeral internal rotation (TR vs. C: +27%/7.814–24.519/1.59/ $p<0.001$; TR vs. TRD:
244 +17%/1.636–19.935/1.83/ $p=0.016$). In TR, the response rate to PRoM in the ankle, knee, hip,
245 shoulder, and glenohumeral joint was 93%, 100%, 93%, 86%, and 86%, respectively (Figure
246 4).

247 Changes in static balance are shown in Table 2. TR demonstrated a greater rise in static
248 balance than C at post-training, which was close to being statistically significant (+143%/-
249 0.784–64.436/0.80/ $p=0.058$) and its response rate to static balance was 86% (Figure 4). No
250 changes were found between TR and TRD at mid- and post-training.

251 Changes in FMS are shown in Table 2. TR and TRD induced a greater rise of the FMS total
252 score than C at mid-training (TR vs. C: +49%/3.860–5.855/6.42/ $p<0.001$; TRD vs. C:
253 +45%/3.431–5.426/5.0/ $p<0.001$) and post-training (TR vs. C: +58%/4.559–
254 6.774/7.71/ $p<0.001$; TRD vs. C: +38%/2.631–4.845/4.0/ $p<0.001$). No changes were reported
255 between TR and TRD at mid-training, but TR had more favorable changes in the FMS total
256 score relative to TRD (+14%/0.716–3.142/2.83/ $p=0.001$) at post-training. In TR, the response
257 rate to the FMS total score was 100% (Figure 4).

258

259 ***Muscular strength***

260 Changes in muscular strength are shown in Figures 2A-D. At mid-training, TR exhibited
261 superior changes than C in chest press (+22%/0.244–12.566/0.82/ $p=0.039$), lat pulldown

262 (+17%/2.767–12.233/1.29/ $p=0.001$), leg extension (+41%/5.986–17.252/2.04/ $p<0.001$), and
 263 leg curl (+27%/4.871–12.796/2.62/ $p<0.001$). TRD demonstrated greater changes than C in
 264 chest press (+33%/3.530–15.851/1.59/ $p=0.001$), lat pulldown (+22%/5.053–
 265 14.519/2.16/ $p<0.001$), leg extension (+39%/5.379–16.645/1.87/ $p<0.001$), and leg curl
 266 (+23%/3.656–11.582/2.05/ $p<0.001$). TR and TRD induced comparable strength gains at mid-
 267 training.

268 At post-training, TR showed greater changes than C in chest press (+29%/2.167–
 269 14.666/1.23/ $p=0.005$), lat pulldown (+25%/6.475–15.977/2.03/ $p<0.001$), leg extension
 270 (+53%/9.133–20.462/2.79/ $p<0.001$), and leg curl (+38%/7.826–16.698/2.71/ $p<0.001$). In leg
 271 curl, TR presented greater changes than TRD (+12%/0.105–9.823/0.91/ $p=0.044$). TRD
 272 exhibited superior changes than C in chest press (+30%/2.296–14.795/1.50/ $p=0.004$), lat
 273 pulldown (+23%/5.511–15.013/2.03/ $p<0.001$), leg extension (+41%/5.633–
 274 16.962/2.23/ $p<0.001$), and leg curl (+23%/2.862–11.733/1.79/ $p=0.001$). In TR, the response
 275 rate to all 1RM measures was 100% (Figure 4).

276

277 ***Muscular endurance***

278 Changes in muscular endurance are shown in Figures 2E-G. At mid-training, TR resulted in
 279 greater changes of muscular endurance than C (curl-up: +75%/11.024– 9.595/3.39/ $p<0.001$;
 280 push-up: (+143%/3.402–11.026/2.04/ $p<0.001$; bodyweight squat: +97%/13.060–
 281 18.559/6.03/ $p<0.001$) and TRD demonstrated superior changes in muscular endurance than C
 282 (curl-up: +87%/13.238–21.810/3.85/ $p<0.001$; push-up: +168%/3.590–11.267/2.56/ $p<0.001$;
 283 bodyweight squat: 102%/11.961–18.658/5.33/ $p<0.001$). TR and TRD resulted in similar
 284 muscular endurance gains.

285 At post-training, TR exhibited greater changes of muscular endurance than C (curl-up:
 286 +103%/16.185–25.196/5.0/ $p<0.001$; push-up: +195%/7.876–15.553/3.14/ $p<0.001$;
 287 bodyweight squat: +136%/18.176–24.872/7.33/ $p<0.001$) and TRD showed superior changes in

288 muscular endurance than C (curl-up: +83%/12.185–21.196/3.27/ $p<0.001$; push-up:
289 +123%/3.590–11.267/1.99/ $p<0.001$; bodyweight squat: +97%/11.961–8.658/4.66/ $p<0.001$).
290 TR had more favorable changes in muscular endurance relative to TRD (push-up: +32%/0.081–
291 8.491/0.80/ $p=0.044$; bodyweight squat: +20%/2.547–9.882/1.69/ $p<0.001$). In TR, the response
292 rate to all muscular endurance measures was 100% (Figure 3).

293

294 FIGURE 2 ABOUT HERE

295

296 TABLE 2 ABOUT HERE

297

298 FIGURE 3 ABOUT HERE

299

300 **Discussion**

301 This 10-month study revealed that the implementation of a HIIT-type, integrated
302 neuromuscular exercise program performed in a real-world gym setting using portable
303 equipment induces considerable improvement of musculoskeletal fitness in previously inactive,
304 **overweight or obese** women. These adaptations were reduced but not lost after prolonged
305 detraining.

306 This trial focused on physically inactive, middle-aged, **overweight or obese** who are
307 characterized by increased cardiometabolic risk (11), poor functional capacity (32), a higher
308 risk for musculoskeletal disorders (42) and physical limitations (19) compared to normoweight
309 women. **Overweight and obese adults** are more prone to sustain injuries and exhibit knee
310 osteoarthritis than individuals of a normal BMI (35). Hence, progressive, injury-free and
311 effective exercise protocols are critical to reduce functional deficits that are responsible for a
312 smaller PRoM in several joints (19), impaired quality of life and a rising prevalence of injuries
313 in this population (17). In this study, a 10-month training program designed for inactive,

314 overweight or obese women was injury-free and reported high adherence and low dropout rates.
315 This outcome may support the necessity of prescribing progressive and supervised exercise
316 regimens for this population aiming to promote a safe exercise experience that may be pivotal
317 for behavioural regulation in exercise (4).

318

319 ***Bone adaptations***

320 The implementation of high-impact training for inactive, middle-aged, **overweight or obese**
321 women is critical for preventing osteopenia, osteoporosis and injuries (20). Training improved
322 whole-body BMD (+1.9%) and BMC (+1.5%) only in TR at post-training indicating that this
323 type of program may meet the essential features of a high-impact, weight-bearing training
324 program capable of activating bone cell mechanisms and hormonal factors. It is worth
325 mentioning that exercise-induced weight loss in this cohort was not accompanied by a decline
326 in BMD as it was seen in **overweight or obese** elderly (40), which is important for bone health
327 and injury prevention.

328

329 ***Flexibility, Static Balance and Mobility***

330 Due to insufficient use of joints in inactive, **overweight or obese** individuals, the
331 functional length of muscles' that cross these joints is reduced resulting in decreased PRoM
332 (19). Hamstring and lower back flexibility improved by 40%, whereas PRoM in ankle, hip,
333 shoulder, glenohumeral joints improved by 24-44% after 10 months of implementation. These
334 adaptations were maintained after 5 months of detraining. These results coincide with a 10-38%
335 increase in flexibility of inactive, **overweight or obese** older adults following long-term RT
336 (13,14,15). These outcomes may be attributed to the features of the protocol, i.e. the
337 incorporation of whole-body multiplanar movements mimicking ADLs. RT may promote
338 flexibility if exercises are performed through a full range of motion to adequately activate both
339 the agonist and antagonist muscle groups (15). Resistive exercises may not only increase muscle

340 mass and contractility but they also improve the strength of tendons and ligaments thereby
341 augmenting joints' P_{RoM} (43). Studies employing compensatory overload models have shown
342 a simultaneous elevation of muscle's strength and tendon's active fibroblast numbers, collagen
343 synthesis and turnover rate (43). The strength of the junction between bone and ligament is also
344 enhanced by this type of training (38). The association between body fat and flexibility
345 performance changes in response to training supports the evidence that body composition may
346 play some role in flexibility and mobility performance in **overweight or obese** adults (19).

347 Although this study did not examine a stretching intervention, it appears that improved
348 P_{RoM} in overweight and obese adults demonstrates exceptional trainability to a hybrid-type
349 exercise training protocol and it may be linked to the improved functionality seen in response
350 to this type of training. The role of flexibility as a major fitness component has been questioned
351 (47). Although the goal of this study was not to determine the value of flexibility as a main
352 fitness component in the overweight and obese population, it appears that P_{RoM} may be pivotal
353 for adequate levels of functionality and quality of life. **DoIT seems not to induce negative**
354 **adaptations to motor control, physical performance and injury rate in a population commonly**
355 **characterized by reduced mobility and functionality despite the lack of static stretching** (47).
356 This is an interesting outcome that highlights the rationale for integrated neuromuscular training
357 methodology adapted for overweight and obese individuals although that static stretching has
358 been classified as a **major component of exercise prescription** for this population (1).

359 Static balance improved by 150%, an adaptation not lost following detraining. This
360 finding complements the marked (+58%) improvement seen in the FMS score suggesting a
361 noticeable improvement in neuromuscular functional status. The large increase in static balance
362 may be related to the low ceiling effect and the relative insensitivity to change of the assessment
363 used, especially in younger individuals without clinical neurological conditions or balance
364 impairments (27). However, sedentary populations with obesity are likely to demonstrate
365 significantly impaired components of motor skills related to fitness such as balance and

366 coordination (19). Thus, a 10-month intervention incorporating various neuromotor exercises
367 into a structured training regimen with a frequency of 3 times per week may reasonably promote
368 a large improvement in this cohort.

369 The FMS testing battery was used as an assessment tool only since its internal and
370 external validity as a predictive tool for injury has been questioned (23). Although there is no
371 data on the effects of various exercise training modalities on the FMS score in untrained,
372 **overweight or obese** adults, this score (<15) for sedentary middle-aged women is considered
373 moderate-to-low (33). Considering that individuals with obesity demonstrate biomechanical
374 deficiencies in ADLs (19), neuromuscular-type protocols may aid to reduce these limitations
375 by using progressive integrated neuromuscular exercises characterized by multiple angles and
376 planes of motion such as bending, lifting, pushing, pulling, carrying, and rotating (22) using
377 non-traditional portable modalities (18). Such training introduces increased cognitive and motor
378 processing demands that ultimately favor not only strength but also body and joint stability,
379 coordination, balance and PRoM. These outcomes are aligned with recent evidence suggesting
380 that the functionality and mobility of **overweight or obese** women be improved through
381 neuromotor training programs (37).

382 Improvements of knee flexor and extensor strength in response to neuromuscular exercise
383 training, as in this study, **are** associated with increased balance and gait (48) that ultimately
384 improves functional status and reduces falls (16). A potential explanation for these adaptations
385 may be related to the increase in LBM and strength that are seen in response to similar protocols
386 (7). Another explanation for static balance adaptations may be linked to the activation of the
387 vermis of the cerebellum, which is the principal part of a central coordinating mechanism (27).
388 Additionally, postural sensibility to convey information concerning position may play an
389 important role for improving the function of sensory pathways and proprioception (27). These
390 findings highlight the need to integrate multicomponent neuromuscular exercise interventions
391 of sufficient power in the muscular system.

392

393 ***Muscular performance adaptations***

394 Strength improved in both upper- (+25-29%) and lower-body (+38-53%) in response to
395 training. Interestingly, detraining did not reverse these gains in upper- (+23-30% vs. pre-
396 training) and lower-body (+23-41% vs. pre-training) musculature. Likewise, muscular
397 endurance increased in upper-body, lower-body and abdominal musculature by 195%, 136%
398 and 103%, respectively. These improvements were also maintained following detraining **in**
399 **upper-body (+104%), lower-body (+73%) and abdominal musculature (+58%) compared to**
400 **baseline levels**. These findings are aligned with previous reports in lean women involved in
401 either a short-term conventional CT or circuit-based whole-body RT (28), suggesting a similar
402 trainability. These results corroborate a previous report of improved musculoskeletal fitness
403 and body composition in response to short-term HIIT-type programs that use a whole-body RT
404 approach (6,25). RT is highly recommended as a fundamental component of an exercise
405 program targeted to preventing, managing and treating obesity while eliciting neuromuscular
406 adaptations in individuals (1). The increase in muscular strength and endurance may be
407 attributed to neuromuscular adaptations (25,28,38) and a rise in DXA-assessed LBM (6).

408

409 ***Detraining***

410 Detraining is a serious issue for **overweight or obese** individuals participating in exercise
411 interventions (26). There are no data for the impact of detraining on the adaptations obtained
412 from hybrid, HIIT-type programs. **In this study, training gains were reduced but not eliminated**
413 **following a 5-month detraining period**. This outcome corroborates previous findings suggesting
414 that musculoskeletal fitness may be maintained above pre-training levels ever after a training
415 cessation of 5 months or longer if previous training was of sufficient intensity (14).
416 Additionally, it has been documented that RT status may limit the type of neural adaptations
417 that are responsible for the increase in muscular strength and probably the speed of reversibility

418 (45). As such, previously untrained individuals are likely to rapidly lose the adaptations induced
419 by short-term (8-12 weeks) RT programs during a detraining period (45). Detraining-induced
420 loss of musculoskeletal fitness seems to be intensity-dependent (14) and may be associated with
421 an attenuation of muscle fiber size and motor unit recruitment efficiency (24).

422

423 ***Practical applications***

424 The outcomes of this study coincide with studies using HIIT-type protocols (34,36)
425 suggesting that ~100 min of training per week without changes in eating patterns and habitual
426 PA may be an effective long-term approach for musculoskeletal fitness improvement in inactive
427 overweight or obese women. Interestingly, prolonged detraining did not abolish the
428 musculoskeletal fitness adaptations obtained from this fully-supervised longitudinal exercise
429 intervention. These findings underline a safe, time-efficient and motivating (4) exercise
430 approach to promote musculoskeletal health in overweight or obese women that may be a
431 valuable addition to current exercise recommendations for this population (1). However, further
432 research is needed in this area investigating the efficacy of such an exercise protocol in males
433 and other age and race groups as previously described (5).

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437

438 **Disclosure of interest**

439 The authors report no conflict of interest.

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Figure 1.

CONSORT diagram of the study.

Figure 2.

Experimental flowchart.

TR, training group (5 months); TRD, training (5 months) - detraining (5 months) group; DoIT, exercise protocol; P_{RoM}, passive range of motion; FMS, functional movement screen; ¹for all groups (4-week adaptive period); ²only for TR and TRD; ³for all groups.

Figure 3.

Changes in muscular strength and endurance throughout the experimental period.

C, control group; TR, training group; TRD, training-detraining group; 1-RM, one repetition maximum; reps, repetitions; † different from Pre, $p < 0.05$; ‡ different from Mid, $p < 0.05$; § different from C, $p < 0.05$; # different from TR, $p < 0.05$.

Figure 4.

Multiple differential responder groups to exercise in TR following a 10-month intervention.

1-RM, one repetition maximum; P_{RoM}, passive range of motion; FMS, functional movement screen.

Supplemental Digital Content 1. The exercises of the 10-month DoIT protocol.

1 **Hybrid Neuromuscular Training Promotes Musculoskeletal Adaptations in**
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3 **Inactive Overweight and Obese Women: A Training-Detraining**
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6 **Randomized Controlled Trial**
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Abstract

This study investigated the effects of a 10-month high-intensity interval-type neuromuscular training program on musculoskeletal fitness in overweight and obese women. Forty-nine inactive females (36.4±4.4 yrs) were randomly assigned to either a control (N=21), a training (N=14, 10 months) or a training-detraining group (N=14, 5 months training followed by 5 months detraining). Training used progressive loaded fundamental movement patterns with prescribed work-to-rest intervals (1:2, 1:1, 2:1) in a circuit fashion (2-3 rounds). Muscular strength and endurance, flexibility, passive range of motion (PRoM), static balance, functional movement screen (FMS) and bone mass density (BMD) and content (BMC) were measured at pre-, mid-, and post-intervention. Ten months of training induced greater changes than the controls in (i) BMD (+1.9%, $p<0.001$) and BMC (+1.5%, $p=0.023$) ii) muscular strength (25%-53%, $p=0.001-0.005$); iii) muscular endurance (103%-195%, $p<0.001$); and iv) mobility (flexibility: 40%, $p<0.001$; PRoM [24%-53%, $p=0.001-0.05$]; balance: 175%, $p=0.058$; FMS: +58%, $p<0.001$). The response rate to training was exceptionally high (86-100%). Five months of detraining reduced but not abolished training-induced adaptations. These results suggest that a hybrid-type exercise approach integrating endurance-based bodyweight drills with resistance-based alternative modes into a real-world gym setting may promote musculoskeletal fitness in overweight or obese women.

Keywords: intermittent exercise; females; muscular strength; mobility; functional movement patterns, bone health.

Word count: 4,361

50 Introduction

51 Obesity is a multifactorial chronic condition affecting one in three adults worldwide (29).
52 Individuals with obesity demonstrate low cardiorespiratory fitness, high metabolic risk and
53 physical limitations (11,32). This population demonstrates biomechanical deficits in activities
54 of daily living (ADL) and reduced passive range of motion (PRoM) in several joints (19)
55 compared to lean individuals. Such kinetic limitations due to restricted musculoskeletal fitness
56 and mobility levels predispose obese individuals to injuries and lead to impaired functionality
57 and reduced quality of life (42). Overweight or obese adults also exhibit a 15% and 48%,
58 respectively, higher risk of sustaining an injury (35) and these rates are even higher for industry
59 workers (17).

60 Musculoskeletal fitness is characterised by lean body mass (LBM), muscular strength and
61 endurance, balance and mobility, which contribute to physical performance, resting metabolic
62 rate improvement, osteoporosis prevention and body functionality in ADL (20). Low
63 musculoskeletal fitness levels may predispose obese adults to hip, foot, ankle, knee and
64 shoulder injuries and may cause soft tissue (cartilage, tendons and fascia) damage (42).
65 Although, the etiology is largely unclear, the overloading of the locomotor apparatus combined
66 with the poor musculoskeletal strength and mobility produce impaired mechanics during
67 movement that increases the stress within the soft tissue and bones (42). Obesity may also be
68 related to a lower bone mineral density (BMD) and content (BMC) (36). Although **overweight**
69 **and obese** adults tend to have higher absolute BMC values than adults of healthy weight, after
70 adjusting for total body mass, their BMC is markedly lower than that of their controls (36). In
71 other words, the elevated BMD usually measured in adults with obesity may not be adequate
72 to offset the greater forces developed during low- or high-velocity movements.

73 Regular exercise is an efficient tool for improving **physical fitness, health and body**
74 **composition** in this population (1). Current exercise guidelines include progressive protocols of
75 continuous endurance training (CET), resistance training (RT), or combined CET and RT

1 76 training (CT) to induce cardiorespiratory, neuromuscular and metabolic adaptations (1).
2
3 77 Structured RT is pivotal for preventing sarcopenia and osteoporosis in sedentary,
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5 78 premenopausal women with obesity through improvements in LBM and physical performance
6
7 79 (21,40). High-intensity interval training (HIIT) is one of the most popular exercise modes (3)
8
9 80 requiring less exercise volume compared to CET, RT, or CT and demonstrating high
10
11 81 compliance rates when conducted under supervision in untrained individuals (34). HIIT
12
13 82 includes repeated short-to-long bouts performed at an intensity that provokes a heart rate (HR)
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15 83 $\geq 80\%$ of maximal hear rate (MHR) (39). The present, injury-free, hybrid-type exercise protocol
16
17 84 integrates progressive HIIT and functional resistance accessory training into a circuit training
18
19 85 format that has been shown to reduce body fat, increase LBM, RMR, endurance, exercise
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21 86 behavioural regulation and vitality with exceptional adherence rates in previously inactive
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23 87 women with obesity (4,6). Such an exercise approach incorporates endurance-based
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25 88 bodyweight drills and resistance-based alternative modalities (18) performed in a circuit,
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27 89 interval format and at moderate-to-high intensity adopting some of the principal characteristics
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29 90 of multimodal integrative neuromuscular training (44).
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37 91 Although there is evidence that overweight or obese adults need comprehensive exercise
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39 92 strategies not only to reduce body mass and fat (1) but also to improve functional limitations
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41 93 while avoiding physical training-related injuries (37), there is a paucity of longitudinal studies
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43 94 to determine the efficacy of such a HIIT-type neuromuscular exercise approach on
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45 95 musculoskeletal fitness, mobility and bone health. Additionally, it is important to investigate
46
47 96 potential changes in such physiological parameters, which result from the cessation of exercise,
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49 97 since exercise training is considered a fundamental component of every lifestyle intervention
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51 98 for this population. It has been observed an unfavorable effect of detraining on neuromuscular
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53 99 performance that was mainly influenced by the duration of training cessation, age, and training
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55 100 status (45). Characteristically, when an 8-month multicomponent exercise program performed
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1 101 by older overweight women was interrupted for only three months, musculoskeletal
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3 102 performance gains induced by previous training were abolished (49).

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5 103 To our knowledge, there is no data concerning the effects of training cessation on
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7 104 musculoskeletal fitness parameters in sedentary overweight and obese individuals. We
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10 105 hypothesized that the training would induce favorable changes in musculoskeletal fitness.
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12 106 Therefore, this study aimed to determine the effects of the a HIIT-type, neuromuscular training
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15 107 protocol on (i) muscular strength and muscular endurance, (ii) joints' range of motion, (iii)
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17 108 balance, (iv) functional movement patterns, and (v) bone health of previously inactive,
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20 109 premenopausal Caucasian women with obesity.

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23 24 111 **Materials and Methods**

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28 29 113 *Study design*

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32 114 This study is a part of a larger longitudinal research project whose purpose, methodology and
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34 115 primary outcomes are reported elsewhere (6). In this investigation, data upon musculoskeletal
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37 116 fitness are presented. This study was a randomised controlled trial based on a three-group,
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39 117 repeated-measures design in accordance with the Consolidated Standards of Reporting Trial
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41
42 118 (CONSORT) guidelines (Figure 1) and it was registered at clinicaltrials.gov as NCT03134781.
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44 119 Initially, 102 participants were assessed for eligibility, 66 were recruited and allocated to three
45
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47 120 groups, and 49 completed the trial as required (see Figure supplemental Digital Content 1).

48
49 121 Participants (36.4 ± 4.4 years) were randomly assigned to a training (TR, $n=14$), a training-
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51 122 detraining group (TRD, $n=14$) or a control (C, $n=21$) group. Following a 4-week adaptive and
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54 123 familiarization period **as previously articulated** (6), TR performed the 10-month exercise
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56 124 training protocol whereas TRD performed the same protocol for 5 months and then entered a
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59 125 5-month detraining period. Abstinence from exercise in the detraining group was verified using
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61 126 accelerometry (GT3X-BT, ActiGraph, FL, USA). Accelerometry data were used in the analysis,
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127 only if participants had ≥ 4 days and ≥ 10 wear hours/day. Four vector magnitude data were used
128 to calculate daily activity and sedentary time. Data were expressed as steps/day and time in
129 sedentary, light, moderate, vigorous and moderate-to-vigorous physical activity as described
130 (6). Assessments of musculoskeletal fitness were performed at pre-, mid-, and post-training
131 (Figure 1). All assessment procedures were completed with the same order (bone health,
132 flexibility, static balance, functional movement patterns, maximal strength, muscle endurance)
133 at pre-, mid- and post-training.

FIGURE 1 ABOUT HERE

Participants

138 Participants were medically cleared for strenuous exercise, were non-smokers and of low
139 regular PA or structured exercise for ≥ 6 months before the study. None of them were on
140 medication, diet or nutritional supplementation. Participants were excluded if they missed
141 $\geq 20\%$ of total exercise sessions, changed their eating habits and modified their PA levels during
142 the intervention. Participants during detraining need to have comparable PA levels with pre-
143 training. Participants were informed about all risks, discomforts and benefits associated with
144 the study and provided a written consent. This investigation was carried out in accordance with
145 the guidelines contained in the 2013 Declaration of Helsinki and was approved by the
146 Institutional Ethics Committee. Participants' characteristics are shown in Table 1.

TABLE 1 ABOUT HERE

Training

151 Three small-group (5-10 participants per session), supervised training sessions per week that
152 used asynchronous music in the background were performed on non-consecutive days for TR

153 (10 months) and TRD (5 months) as previously reported (6). This hybrid-type protocol was
154 organized in four progressive training phases (i.e., phase 1: weeks 1-7, phase 2: weeks 8-14,
155 phase 3: weeks 15-20 and phase 4: 21-40) (Figure 1). The mean weekly exercise volume was
156 ~100 min, net exercise time was 6.5-24.0 min per session and total duration per session was
157 23-41 min (6). Exercises (see Table, Supplemental Digital Content 2) adapted basic movement
158 patterns (squat, hinge, lunge, push, pull, carry, rotation, plank) utilizing portable modalities
159 (suspension belts, balance balls, kettlebells, medicine balls, battle ropes, stability balls, speed
160 ladders, foam rollers, elastic bands) and bodyweight as resistance. Exercises (~10-12 per
161 session) were organized in a circuit format and performed in all planes of motion simulating
162 ADLs. The work-to-rest ratio was varied (1:2, 1:1, 2:1) using an interval duration of 20-40 sec
163 to provide progression (see Table, Supplemental Digital Content 2) (6). Verbal encouragement
164 was provided. Participants were instructed to execute as many repetitions as possible with the
165 correct form and with a controlled, moderate rhythm. A 10-min warm-up and a 5-min cool
166 down period was applied in all sessions (6). HR was monitored and recorded using telemetry
167 (Polar Team Solution, Polar Electro-Oy, Kempele, Finland) aiming to maintain an intensity
168 $\geq 75\%$ of MHR throughout each session. Rating (6-20) of perceived exertion (RPE) was
169 recorded at the end of each round in all sessions using the 6-20 Borg scale.

171 *Measurements*

173 *Bone Health*

174 Whole-body BMC and BMD were performed using a dual energy X-ray absorptiometry (DXA)
175 scanner (GE Healthcare, Lunar DPX-NT) in the morning by the same experienced radiologist
176 according to standard procedures (41). Briefly, participants were placed in a supine position
177 with their body aligned along the central horizontal axis, their arms parallel to their body
178 (without touching it), the forearms pronated, hands flat, legs fully extended, and feet secured

179 using a velcro strap to prevent foot movement during the scan. The instrument was calibrated
180 daily using a calibration epoxy resin phantom. All analyses were performed using the 12.2 GE
181 enCORE software package.

182

183 *Flexibility, Static Balance and Mobility*

184 A 3-min cycling warm-up preceded mobility testing (three consecutive measurements).

185 Flexibility of lower back and hamstrings was measured under standardized conditions using the

186 modified sit-and-reach test (2). Goniometry (Lafayette 01135, Lafayette Instrument Inc.,

187 Lafayette, IN, USA) was applied to assess the PRoM (in degrees) of ankle dorsiflexion, knee

188 extension, hip extension, shoulder extension, and glenohumeral internal rotation (31). Both

189 extremities were examined and the median of their measurements was reported as the value in

190 goniometry.

191 Static balance was assessed using the modified Romberg test. Participants were asked to

192 stand without shoes on a firm surface, with eyes closed and arms crossed on the chest and the

193 dominant foot placed directly in front of the non-dominant foot. The time to failure was

194 measured manually by stopwatch in sec (30).

195 The Functional Movement Screening (FMS) with an ICC of >0.8 was used to evaluate

196 functional mobility, postural stability and movement behavior in different settings (23). Two

197 examiners (with an intra-rater reliability of 88.6%) performed this assessment. The FMS has

198 been reported as a simple, quick, non-invasive and suitable movement-based assessment tool

199 for middle-aged, **overweight or obese** aiming to evaluate their functional capacity levels (23).

200 In brief, the FMS assesses seven fundamental movement tasks (deep squat, hurdle step, in-line

201 lunge, active straight-leg raise, trunk stability push-up, rotary stability, shoulder mobility). Each

202 movement task was scored from 0 to 3 points (0=pain with pattern regardless of quality,

203 1=unable to perform pattern, 2=able to perform pattern with compensation/imperfection,

204 3=able to perform pattern as directed) and their sum provided the total score ranging from 0 to
205 21 points (46).

206

207 *Muscular Strength and Endurance*

208 Maximal isotonic strength (one repetition maximal, 1RM) was assessed using standard
209 procedures for novice and untrained individuals following familiarization as previously
210 described (2) with an intra-class correlation coefficient (ICC) for test-retest trials of 0.88. Two
211 upper-body (vertical chest press, supinated closed-grip lat pulldown) and two lower-body
212 (seated leg extension, lying leg curl) exercises performed on traditional strength training
213 equipment (Panatta Sport, Apiro, Italy) were selected. Muscular endurance was assessed using
214 timed tests for the abdominal (partial curl-up), upper-body (modified kneeling push-up) and
215 lower-body (modified chair squat) musculature (2). All tests required the participants to
216 perform as many repetitions as possible within 60 sec using standard procedures and a 5-min
217 rest was provided between tests (2).

218

219 *Statistical Analyses*

220 A preliminary power analysis (effect size >0.55 , probability error of 0.05, two-tailed alpha
221 level, power of 0.9) using the G*Power 3.0.10 program based on the study design suggested
222 that a sample of 36-40 participants was necessary to identify statistically meaningful trial
223 effects. For all dependent variables, differences (for both “between” and “within” groups) of
224 means (MD) and confidence intervals (CI) were calculated based on mixed models. Cohen’s *d*
225 criteria were used to interpret the magnitude of MD as very small, small, medium, large, very
226 large and huge for values 0.01, 0.20, 0.50, 0.80, 1.20 and 2.0, respectively. No assumptions
227 were made for covariance matrices (unstructured) since repetitions were not that many to
228 significantly reduce the degrees of freedom. All estimations were corrected based on the
229 Bonferroni criterion for multiple comparisons. Results are presented as relative difference in

230 time ($\Delta\%$). Since the variability of the change score in the intervention groups was greater than
231 that in C, the response rate was analysed using the number of differential responders relative to
232 the ratio of variance in TR and C groups providing multiple differential responder groups (10).
233 Statistical significance was set at $p < 0.05$. Data were analysed using the SPSS 22.0 software
(IBM Corp., Armonk, NY, USA).

Results

237 No injuries or other adverse effects occurred during the trial. Adherence rates for TR (10-month
238 intervention) and TRD (5-month intervention) were 93.5% and 82.6%, respectively, and a 4%
239 dropout rate was reported. Results are described in brackets as $\Delta\%/95\% \text{ CI}/d/p$ levels.

Bone mineral density and bone mineral content

242 Changes in BMD and BMC are shown in Table 2. No changes were observed between TR and
243 TRD. TR only improved BMD following training (Table 2) ($+1.9\%/0.010\text{--}0.035/2.61/p < 0.001$)
244 and BMC ($+1.5\%/0.04\text{--}0.076/2.72/p = 0.023$) and its response rate to whole-body BMD was
245 100% (Figure 4).

Flexibility, Static Balance and Mobility

248 Changes in flexibility and passive range of motion are shown in Table 2. At mid-training, TR
249 and TRD demonstrated greater flexibility changes than C (TR vs. C: $+38\%/3.939\text{--}$
250 $16.490/1.66/p = 0.001$; TRD vs. C: $+34\%/3.010\text{--}15.561/1.31/p = 0.002$). At post-training, TR and
251 TRD elicited more favorable changes in flexibility than C (TR vs. C: $+40\%/4.465\text{--}$
252 $17.130/1.83/p < 0.001$; TRD vs. C: $+26\%/0.572\text{--}13.238/1.02/p = 0.028$). No significant
253 differences were observed between TR and TRD. In TR, the response rate to flexibility was
254 100% (Figure 4).

255 Changes in PRoM are shown in Table 2. At mid training, TR and TRD showed significant
 256 differences than C in hip extension (TR vs. C: +43%/0.678–9.607/1.08/ $p=0.019$; TRD vs. C:
 257 +41%/0.393–9.322/1.08/ $p=0.029$), glenohumeral internal rotation (TR vs. C: +24%/5.676–
 258 22.991/1.45/ $p<0.001$; TRD vs. C: +17%/1.747–19.062/1.04/ $p=0.014$). No changes were noted
 259 between TR and TRD. At post-training, TR demonstrated a trend for a rise in PRoM compared
 260 to C in ankle dorsiflexion (+44%/-0.543–10.924/0.86/ $p=0.088$) and shoulder extension
 261 (+24%/0.178–15.940/0.93/ $p=0.057$). TR elicited greater PRoM changes than C and TRD in
 262 glenohumeral internal rotation (TR vs. C: +27%/7.814–24.519/1.59/ $p<0.001$; TR vs. TRD:
 263 +17%/1.636–19.935/1.83/ $p=0.016$). In TR, the response rate to PRoM in the ankle, knee, hip,
 264 shoulder, and glenohumeral joint was 93%, 100%, 93%, 86%, and 86%, respectively (Figure
 265 4).

266 Changes in static balance are shown in Table 2. TR demonstrated a greater rise in static
 267 balance than C at post-training, which was close to being statistically significant (+143%/-
 268 0.784–64.436/0.80/ $p=0.058$) and its response rate to static balance was 86% (Figure 4). No
 269 changes were found between TR and TRD at mid- and post-training.

270 Changes in FMS are shown in Table 2. TR and TRD induced a greater rise of the FMS total
 271 score than C at mid-training (TR vs. C: +49%/3.860–5.855/6.42/ $p<0.001$; TRD vs. C:
 272 +45%/3.431–5.426/5.0/ $p<0.001$) and post-training (TR vs. C: +58%/4.559–
 273 6.774/7.71/ $p<0.001$; TRD vs. C: +38%/2.631–4.845/4.0/ $p<0.001$). No changes were reported
 274 between TR and TRD at mid-training, but TR had more favorable changes in the FMS total
 275 score relative to TRD (+14%/0.716–3.142/2.83/ $p=0.001$) at post-training. In TR, the response
 276 rate to the FMS total score was 100% (Figure 4).

278 ***Muscular strength***

279 Changes in muscular strength are shown in Figures 2A-D. At mid-training, TR exhibited
 280 superior changes than C in chest press (+22%/0.244–12.566/0.82/ $p=0.039$), lat pulldown

281 (+17%/2.767–12.233/1.29/ $p=0.001$), leg extension (+41%/5.986–17.252/2.04/ $p<0.001$), and
 282 leg curl (+27%/4.871–12.796/2.62/ $p<0.001$). TRD demonstrated greater changes than C in
 283 chest press (+33%/3.530–15.851/1.59/ $p=0.001$), lat pulldown (+22%/5.053–
 284 14.519/2.16/ $p<0.001$), leg extension (+39%/5.379–16.645/1.87/ $p<0.001$), and leg curl
 285 (+23%/3.656–11.582/2.05/ $p<0.001$). TR and TRD induced comparable strength gains at mid-
 286 training.

287 At post-training, TR showed greater changes than C in chest press (+29%/2.167–
 288 14.666/1.23/ $p=0.005$), lat pulldown (+25%/6.475–15.977/2.03/ $p<0.001$), leg extension
 289 (+53%/9.133–20.462/2.79/ $p<0.001$), and leg curl (+38%/7.826–16.698/2.71/ $p<0.001$). In leg
 290 curl, TR presented greater changes than TRD (+12%/0.105–9.823/0.91/ $p=0.044$). TRD
 291 exhibited superior changes than C in chest press (+30%/2.296–14.795/1.50/ $p=0.004$), lat
 292 pulldown (+23%/5.511–15.013/2.03/ $p<0.001$), leg extension (+41%/5.633–
 293 16.962/2.23/ $p<0.001$), and leg curl (+23%/2.862–11.733/1.79/ $p=0.001$). In TR, the response
 294 rate to all 1RM measures was 100% (Figure 4).

295

296 ***Muscular endurance***

297 Changes in muscular endurance are shown in Figures 2E-G. At mid-training, TR resulted in
 298 greater changes of muscular endurance than C (curl-up: +75%/11.024– 9.595/3.39/ $p<0.001$;
 299 push-up: (+143%/3.402–11.026/2.04/ $p<0.001$; bodyweight squat: +97%/13.060–
 300 18.559/6.03/ $p<0.001$) and TRD demonstrated superior changes in muscular endurance than C
 301 (curl-up: +87%/13.238–21.810/3.85/ $p<0.001$; push-up: +168%/3.590–11.267/2.56/ $p<0.001$;
 302 bodyweight squat: 102%/11.961–18.658/5.33/ $p<0.001$). TR and TRD resulted in similar
 303 muscular endurance gains.

304 At post-training, TR exhibited greater changes of muscular endurance than C (curl-up:
 305 +103%/16.185–25.196/5.0/ $p<0.001$; push-up: +195%/7.876–15.553/3.14/ $p<0.001$;
 306 bodyweight squat: +136%/18.176–24.872/7.33/ $p<0.001$) and TRD showed superior changes in

307 muscular endurance than C (curl-up: +83%/12.185–21.196/3.27/ $p<0.001$; push-up:
308 +123%/3.590–11.267/1.99/ $p<0.001$; bodyweight squat: +97%/11.961–8.658/4.66/ $p<0.001$).
309 TR had more favorable changes in muscular endurance relative to TRD (push-up: +32%/0.081–
310 8.491/0.80/ $p=0.044$; bodyweight squat: +20%/2.547–9.882/1.69/ $p<0.001$). In TR, the response
311 rate to all muscular endurance measures was 100% (Figure 3).

FIGURE 2 ABOUT HERE

TABLE 2 ABOUT HERE

FIGURE 3 ABOUT HERE

Discussion

312 This 10-month study revealed that the implementation of a HIIT-type, integrated
313 neuromuscular exercise program performed in a real-world gym setting using portable
314 equipment induces considerable improvement of musculoskeletal fitness in previously inactive,
315 **overweight or obese** women. These adaptations were reduced but not lost after prolonged
316 detraining.

317 This trial focused on physically inactive, middle-aged, **overweight or obese** who are
318 characterized by increased cardiometabolic risk (11), poor functional capacity (32), a higher
319 risk for musculoskeletal disorders (42) and physical limitations (19) compared to normoweight
320 women. **Overweight and obese adults** are more prone to sustain injuries and exhibit knee
321 osteoarthritis than individuals of a normal BMI (35). Hence, progressive, injury-free and
322 effective exercise protocols are critical to reduce functional deficits that are responsible for a
323 smaller P_{RoM} in several joints (19), impaired quality of life and a rising prevalence of injuries
324 in this population (17). In this study, a 10-month training program designed for inactive,

333 overweight or obese women was injury-free and reported high adherence and low dropout rates.

334 This outcome may support the necessity of prescribing progressive and supervised exercise

335 regimens for this population aiming to promote a safe exercise experience that may be pivotal

336 for behavioural regulation in exercise (4).

337

338 ***Bone adaptations***

339 The implementation of high-impact training for inactive, middle-aged, **overweight or obese**

340 women is critical for preventing osteopenia, osteoporosis and injuries (20). Training improved

341 whole-body BMD (+1.9%) and BMC (+1.5%) only in TR at post-training indicating that this

342 type of program may meet the essential features of a high-impact, weight-bearing training

343 program capable of activating bone cell mechanisms and hormonal factors. It is worth

344 mentioning that exercise-induced weight loss in this cohort was not accompanied by a decline

345 in BMD as it was seen in **overweight or obese** elderly (40), which is important for bone health

346 and injury prevention.

347

348 ***Flexibility, Static Balance and Mobility***

349 Due to insufficient use of joints in inactive, **overweight or obese** individuals, the

350 functional length of muscles' that cross these joints is reduced resulting in decreased PRoM

351 (19). Hamstring and lower back flexibility improved by 40%, whereas PRoM in ankle, hip,

352 shoulder, glenohumeral joints improved by 24-44% after 10 months of implementation. These

353 adaptations were maintained after 5 months of detraining. These results coincide with a 10-38%

354 increase in flexibility of inactive, **overweight or obese** older adults following long-term RT

355 (13,14,15). These outcomes may be attributed to the features of the protocol, i.e. the

356 incorporation of whole-body multiplanar movements mimicking ADLs. RT may promote

357 flexibility if exercises are performed through a full range of motion to adequately activate both

358 the agonist and antagonist muscle groups (15). Resistive exercises may not only increase muscle

1 359 mass and contractility but they also improve the strength of tendons and ligaments thereby
2
3 360 augmenting joints' P_{RoM} (43). Studies employing compensatory overload models have shown
4
5 361 a simultaneous elevation of muscle's strength and tendon's active fibroblast numbers, collagen
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7 362 synthesis and turnover rate (43). The strength of the junction between bone and ligament is also
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10 363 enhanced by this type of training (38). The association between body fat and flexibility
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12 364 performance changes in response to training supports the evidence that body composition may
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15 365 play some role in flexibility and mobility performance in **overweight or obese** adults (19).

16
17 366 Although this study did not examine a stretching intervention, it appears that improved
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19
20 367 P_{RoM} in overweight and obese adults demonstrates exceptional trainability to a hybrid-type
21
22 368 exercise training protocol and it may be linked to the improved functionality seen in response
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25 369 to this type of training. The role of flexibility as a major fitness component has been questioned
26
27 370 (47). Although the goal of this study was not to determine the value of flexibility as a main
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29
30 371 fitness component in the overweight and obese population, it appears that P_{RoM} may be pivotal
31
32 372 for adequate levels of functionality and quality of life. **DoIT seems not to induce negative**
33
34 373 **adaptations to motor control, physical performance and injury rate in a population commonly**
35
36
37 374 **characterized by reduced mobility and functionality despite the lack of static stretching** (47).
38
39 375 This is an interesting outcome that highlights the rationale for integrated neuromuscular training
40
41
42 376 methodology adapted for overweight and obese individuals although that static stretching has
43
44 377 been classified as a **major component of exercise prescription** for this population (1).

45
46 378 Static balance improved by 150%, an adaptation not lost following detraining. This
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49 379 finding complements the marked (+58%) improvement seen in the FMS score suggesting a
50
51 380 noticeable improvement in neuromuscular functional status. The large increase in static balance
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53
54 381 may be related to the low ceiling effect and the relative insensitivity to change of the assessment
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56 382 used, especially in younger individuals without clinical neurological conditions or balance
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59 383 impairments (27). However, sedentary populations with obesity are likely to demonstrate
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61 384 significantly impaired components of motor skills related to fitness such as balance and
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1 385 coordination (19). Thus, a 10-month intervention incorporating various neuromotor exercises
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3 386 into a structured training regimen with a frequency of 3 times per week may reasonably promote
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5 387 a large improvement in this cohort.
6

7 388 The FMS testing battery was used as an assessment tool only since its internal and
8
9
10 389 external validity as a predictive tool for injury has been questioned (23). Although there is no
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12 390 data on the effects of various exercise training modalities on the FMS score in untrained,
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15 391 **overweight or obese** adults, this score (<15) for sedentary middle-aged women is considered
16
17 392 moderate-to-low (33). Considering that individuals with obesity demonstrate biomechanical
18
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20 393 deficiencies in ADLs (19), neuromuscular-type protocols may aid to reduce these limitations
21
22 394 by using progressive integrated neuromuscular exercises characterized by multiple angles and
23
24
25 395 planes of motion such as bending, lifting, pushing, pulling, carrying, and rotating (22) using
26
27 396 non-traditional portable modalities (18). Such training introduces increased cognitive and motor
28
29
30 397 processing demands that ultimately favor not only strength but also body and joint stability,
31
32 398 coordination, balance and PRoM. These outcomes are aligned with recent evidence suggesting
33
34 399 that the functionality and mobility of **overweight or obese** women be improved through
35
36
37 400 neuromotor training programs (37).
38

39 401 Improvements of knee flexor and extensor strength in response to neuromuscular exercise
40
41
42 402 training, as in this study, **are** associated with increased balance and gait (48) that ultimately
43
44 403 improves functional status and reduces falls (16). A potential explanation for these adaptations
45
46
47 404 may be related to the increase in LBM and strength that are seen in response to similar protocols
48
49 405 (7). Another explanation for static balance adaptations may be linked to the activation of the
50
51
52 406 vermis of the cerebellum, which is the principal part of a central coordinating mechanism (27).
53
54 407 Additionally, postural sensibility to convey information concerning position may play an
55
56
57 408 important role for improving the function of sensory pathways and proprioception (27). These
58
59 409 findings highlight the need to integrate multicomponent neuromuscular exercise interventions
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61 410 of sufficient power in the muscular system.
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411

412 *Muscular performance adaptations*

413 Strength improved in both upper- (+25-29%) and lower-body (+38-53%) in response to
414 training. Interestingly, detraining did not reverse these gains in upper- (+23-30% vs. pre-
415 training) and lower-body (+23-41% vs. pre-training) musculature. Likewise, muscular
416 endurance increased in upper-body, lower-body and abdominal musculature by 195%, 136%
417 and 103%, respectively. These improvements were also maintained following detraining **in**
418 **upper-body (+104%), lower-body (+73%) and abdominal musculature (+58%) compared to**
419 **baseline levels**. These findings are aligned with previous reports in lean women involved in
420 either a short-term conventional CT or circuit-based whole-body RT (28), suggesting a similar
421 trainability. These results corroborate a previous report of improved musculoskeletal fitness
422 and body composition in response to short-term HIIT-type programs that use a whole-body RT
423 approach (6,25). RT is highly recommended as a fundamental component of an exercise
424 program targeted to preventing, managing and treating obesity while eliciting neuromuscular
425 adaptations in individuals (1). The increase in muscular strength and endurance may be
426 attributed to neuromuscular adaptations (25,28,38) and a rise in DXA-assessed LBM (6).

427

428 *Detraining*

429 Detraining is a serious issue for **overweight or obese** individuals participating in exercise
430 interventions (26). There are no data for the impact of detraining on the adaptations obtained
431 from hybrid, HIIT-type programs. **In this study, training gains were reduced but not eliminated**
432 **following a 5-month detraining period**. This outcome corroborates previous findings suggesting
433 that musculoskeletal fitness may be maintained above pre-training levels ever after a training
434 cessation of 5 months or longer if previous training was of sufficient intensity (14).
435 Additionally, it has been documented that RT status may limit the type of neural adaptations
436 that are responsible for the increase in muscular strength and probably the speed of reversibility

1 437 (45). As such, previously untrained individuals are likely to rapidly lose the adaptations induced
2
3 438 by short-term (8-12 weeks) RT programs during a detraining period (45). Detraining-induced
4
5 439 loss of musculoskeletal fitness seems to be intensity-dependent (14) and may be associated with
6
7 440 an attenuation of muscle fiber size and motor unit recruitment efficiency (24).
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10 441

11 12 442 ***Practical applications***

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14
15 443 The outcomes of this study coincide with studies using HIIT-type protocols (34,36)
16
17 444 suggesting that ~100 min of training per week without changes in eating patterns and habitual
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19
20 445 PA may be an effective long-term approach for musculoskeletal fitness improvement in inactive
21
22 446 overweight or obese women. Interestingly, prolonged detraining did not abolish the
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24
25 447 musculoskeletal fitness adaptations obtained from this fully-supervised longitudinal exercise
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27 448 intervention. These findings underline a safe, time-efficient and motivating (4) exercise
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30 449 approach to promote musculoskeletal health in overweight or obese women that may be a
31
32 450 valuable addition to current exercise recommendations for this population (1). However, further
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35 451 research is needed in this area investigating the efficacy of such an exercise protocol in males
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37 452 and other age and race groups as previously described (5).
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3
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6
7 455 and impressive commitment of the participants.

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13 457 **Disclosure of interest**

14
15 458 The authors report no conflict of interest.

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1 **Figure 1.**

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3 CONSORT diagram of the study.
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8 **Figure 2.**

9 Experimental flowchart.

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12 TR, training group (5 months); TRD, training (5 months) - detraining (5 months) group; DoIT,
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14 exercise protocol; PRoM, passive range of motion; FMS, functional movement screen; ¹for all
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16 groups (4-week adaptive period); ²only for TR and TRD; ³for all groups.
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26 **Figure 3.**

27 Changes in muscular strength and endurance throughout the experimental period.

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29 C, control group; TR, training group; TRD, training-detraining group; 1-RM, one repetition
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31 maximum; reps, repetitions; † different from Pre, $p < 0.05$; ‡ different from Mid, $p < 0.05$; §
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33 different from C, $p < 0.05$; # different from TR, $p < 0.05$.
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43 **Figure 4.**

44 Multiple differential responder groups to exercise in TR following a 10-month intervention.

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47 1-RM, one repetition maximum; PRoM, passive range of motion; FMS, functional movement
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49 screen.
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Supplemental Digital Content 1. The exercises of the 10-month DoIT protocol.

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Table 1.

Participants' baseline characteristics (range of values are shown in parentheses).

	C (n = 21)	TR (n = 14)	TRD (n = 14)
Age (yrs)	36.0 ± 4.2 (30.0 – 44.0)	36.4 ± 5.0 (30.0 – 45.0)	36.9 ± 4.3 (30.0 – 45.0)
Body mass (kg)	80.2 ± 8.9 (69.0 – 103.0)	78.0 ± 9.9 (64.0 – 97.5)	78.7 ± 7.9 (68.0 – 91.0)
Body height (m)	1.65 ± 0.5 (1.55 – 1.75)	1.66 ± 0.5 (1.60 – 1.77)	1.64 ± 0.6 (1.55 – 1.76)
BMI (kg·m ⁻²)	29.6 ± 3.0 (27.0 – 33.6)	28.2 ± 2.8 (25.9 – 34.3)	29.1 ± 3.0 (26.9 – 31.5)
PA (steps·day ⁻¹)	6,400 ± 1,851 (2,694 – 9,025)	6,331 ± 1,042 (4,358 – 8,676)	6,870 ± 2,031 (2,865 – 9,452)
Body fat (%)	46.7 ± 6.5 (35.7 – 58.3)	47.5 ± 3.2 (41.4 – 53.2)	46.2 ± 3.9 (38.0 – 52.5)

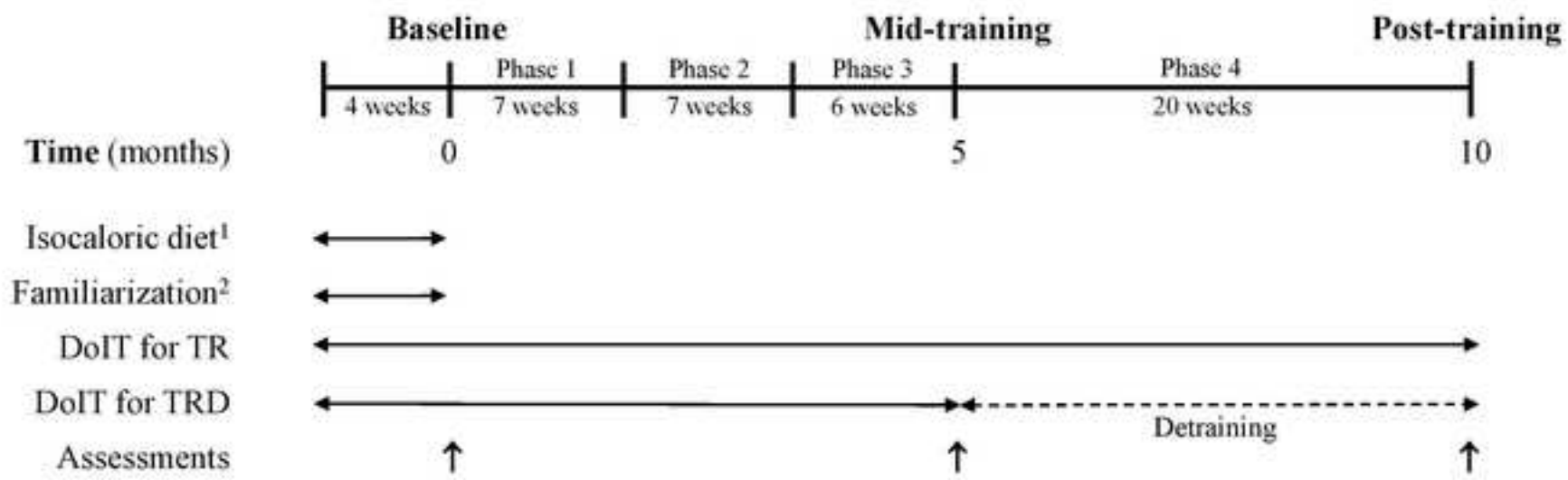
C, control group; TR, training group; TRD, training-detraining group; BMI, body mass index; PA, physical activity; Data are means ± SD.

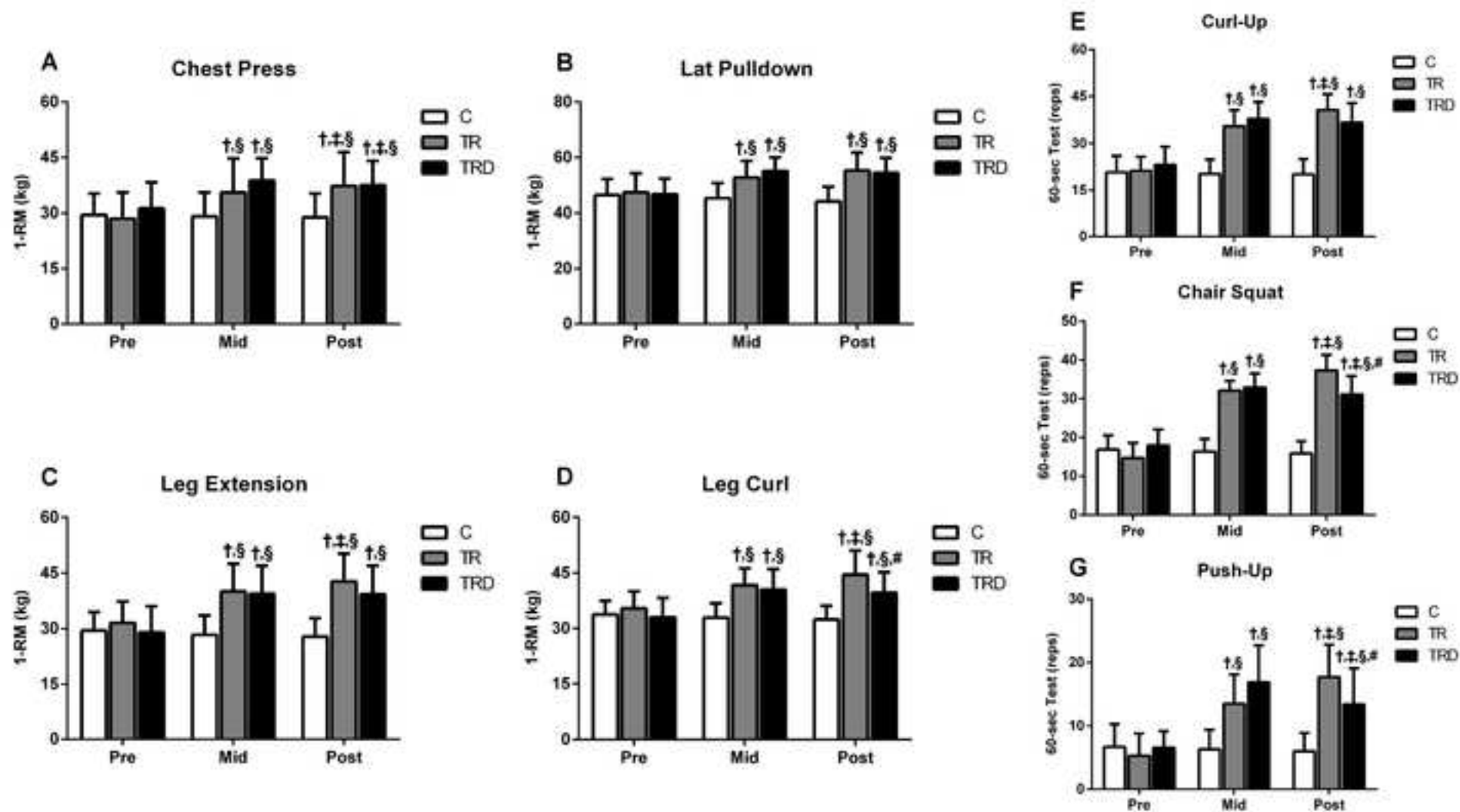
Table 2. Changes in flexibility, passive range of motion, static balance, FMS and bone health throughout the experimental period.

Variables	C			TR			TRD		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Modified sit and reach (cm)	27.3 ± 7.0	27.1 ± 6.7	27.0 ± 6.7	28.1 ± 6.5	37.3 ± 6.6 †,§	37.8 ± 6.9 †,‡,§	27.7 ± 8.1	36.4 ± 8.8 †,§	33.9 ± 8.6 †,‡,§
Ankle dorsiflexion (deg.)	12.0 ± 7.0	12.1 ± 6.9	11.8 ± 7.0	11.3 ± 7.7	16.1 ± 8.6 †	17.0 ± 7.6 †	11.7 ± 6.4	14.9 ± 5.4	13.8 ± 4.9
Knee extension (deg.)	41.0 ± 30.9	41.4 ± 31.1	41.9 ± 30.8	34.5 ± 9.3	21.6 ± 8.3 †	21.6 ± 8.2 †	43.0 ± 37.7	35.6 ± 40.3 †	37.4 ± 38.7 †,‡
Hip extension (deg.)	12.3 ± 6.3	12.1 ± 5.7	11.8 ± 5.6	12.7 ± 6.8	17.3 ± 4.5 †,§	18.1 ± 4.6 †,§	11.1 ± 5.1	17.0 ± 5.0 †,§	15.4 ± 4.7 †
Shoulder extension (deg.)	33.1 ± 10.8	32.8 ± 10.0	32.5 ± 9.9	33.5 ± 11.5	39.5 ± 9.1 †	40.4 ± 8.3 †,‡,§	31.6 ± 9.6	39.8 ± 10.0 †	37.3 ± 9.7 †,‡
Glenohumeral rotation (deg.)	60.3 ± 12.8	59.8 ± 12.3	59.5 ± 12.5	67.1 ± 11.2	74.1 ± 7.8 †,§	75.6 ± 6.9 †,§	58.6 ± 10.8	70.2 ± 8.1 †,§	64.9 ± 7.0 †,‡,#
Sharpened Romberg (sec)	24.1 ± 16.3	22.8 ± 14.5	22.3 ± 13.9	21.7 ± 26.3	37.4 ± 36.8	54.2 ± 61.2 †	23.8 ± 18.4	40.2 ± 36.7	33.9 ± 32.7
FMS (total score)	10.00 ± 1.10	9.86 ± 1.28	9.76 ± 1.09	10.14 ± 1.51	14.71 ± 0.73 †,§	15.43 ± 0.65 †,‡,§	10.29 ± 1.14	14.29 ± 1.13 †,§	13.50 ± 1.91 †,‡,§,#
Whole-body BMD (g/cm ²)	1.192 ± 0.063	1.194 ± 0.064	1.193 ± 0.063	1.180 ± 0.060	1.187 ± 0.056	1.202 ± 0.058 †,‡	1.196 ± 0.066	1.201 ± 0.066	1.195 ± 0.066
Whole-body BMC (g/cm ²)	2.576 ± 0.24	2.574 ± 0.24	2.573 ± 0.24	2.599 ± 0.21	2.609 ± 0.23	2.639 ± 0.22 †	2.587 ± 0.24	2.598 ± 0.26	2.589 ± 0.25

C, control group; TR, training group; TRD, training-detraining group; FMS, functional movement screen; BMD, body mineral density; BMC, body mineral content; † different from Pre, $p < 0.05$; ‡ different from Mid, $p < 0.05$; § different from C, $p < 0.05$; # different from TR, $p < 0.05$.

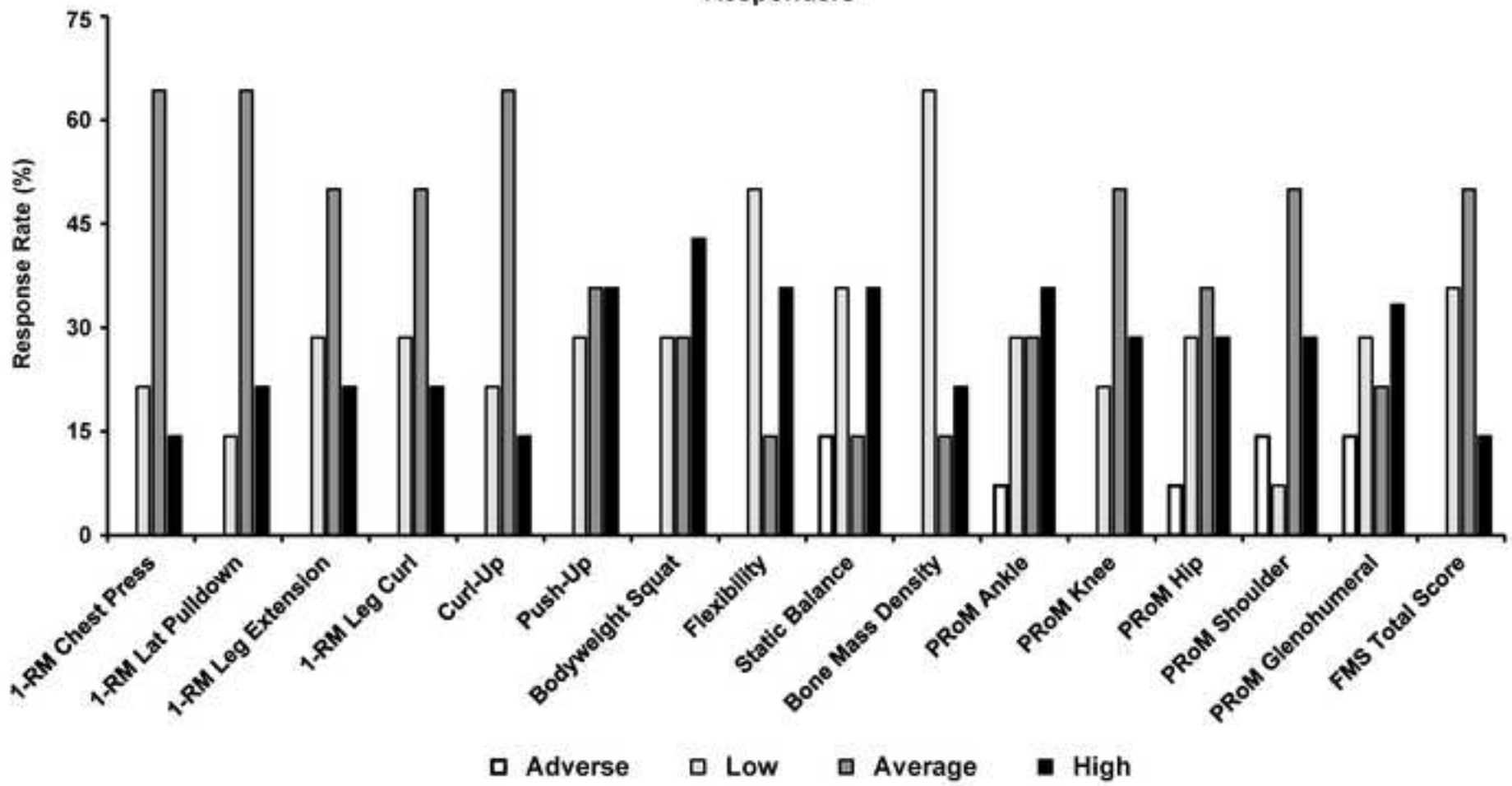
Figure





Figure

Responders

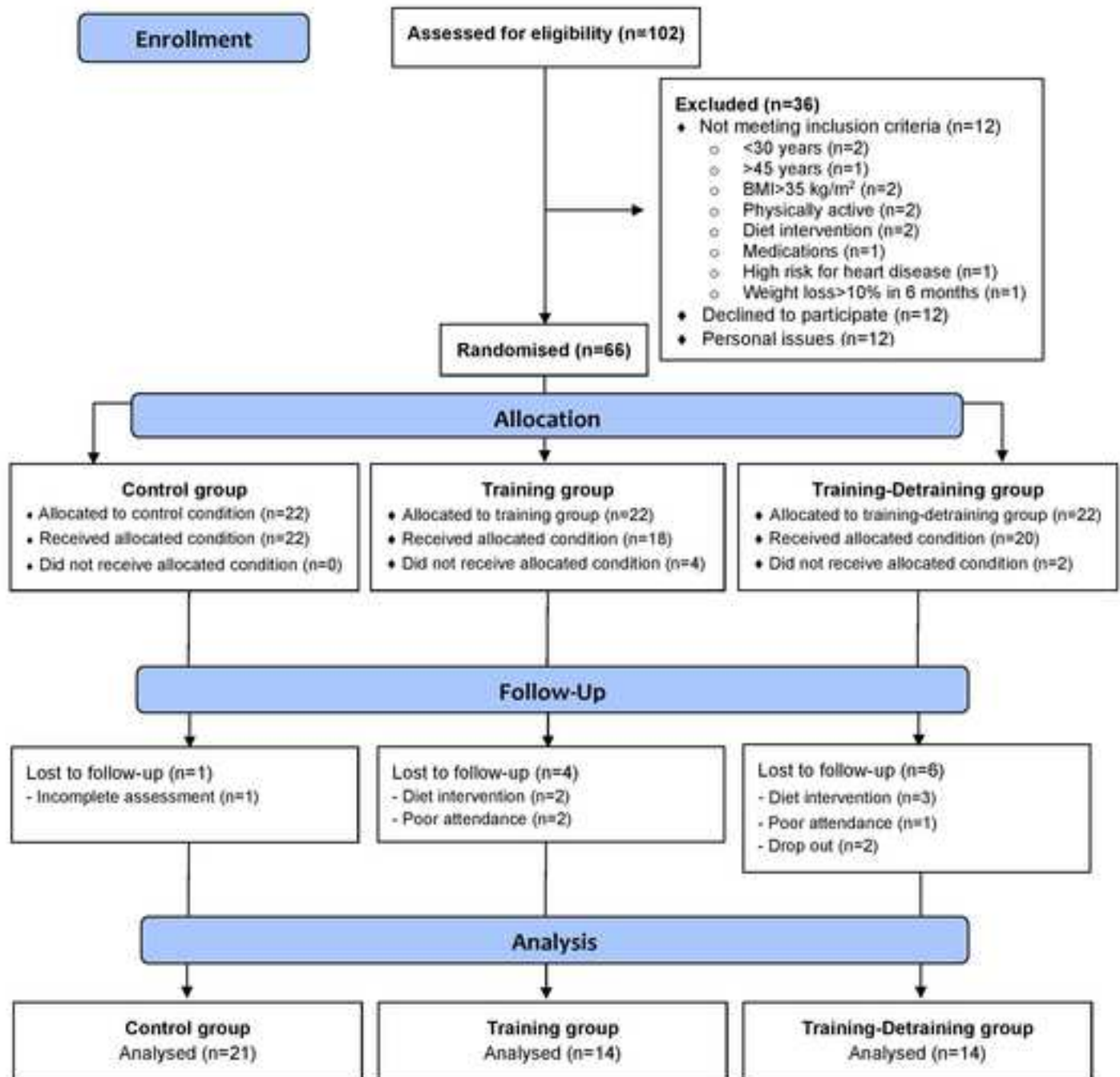




CONSORT

TRANSPARENT REPORTING of TRIALS

CONSORT 2010 Flow Diagram



Supplemental Digital Content 1. The exercises of the training protocol.

Adjunct Modalities	Exercises			
	Phase 1	Phase 2	Phase 3	Phase 4
1 – Balance Ball	Over dome ankle touch	Straddle jump	Split jack	Over dome hand touch
2 – Suspension Exercise Device	Neutral grip row	Wide grip row	Y deltoid raise	Chest press
3 – Kettlebell	Sumo deadlift	Sumo deadlift high pull	Two-arm swing	Two-arm snatch
4 – Bodyweight	Straight-arm plank	Forearm plank	Straight-arm reverse plank	Side plank rotation
5 – Speed Ladder	Low knee skip	Lateral shuffle	Heel flick	High knee skip
6 – Battling Rope	Bilateral wave	Alternating wave	Side-to-side wave	Slam
7 – Medicine Ball	Alternating static lunge	Forward lunge with press	Lunge to chest pass	Twisting chop
8 – Foam Roller	Forearm plank	Forearm plank with leg lift	Shifting Plank	Forearm plank with leg lift
9 – Bodyweight	Jumping jack	Split jack	Ice skater	Burpee
10 – Resistance Band with Stick	Squat to overhead press	Lateral shuffle press	Hockey slap shot	Axe chop
11 – Resistance Band		Squat row	Reverse fly with lunge	Squat to overhead press
12 – Medicine Ball			Squat throw	Swing

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Body fat (%)	46.7 ± 6.5 (35.7 – 58.3)	47.5 ± 3.2 (41.4 – 53.2)	46.2 ± 3.9 (38.0 – 52.5)

C, control group; TR, training group; TRD, training-detraining group; BMI, body mass index; PA, physical activity; Data are means ± SD.

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12 – Medicine Ball			Squat throw	Swing

Supplemental Digital Content 1. The characteristics of the training protocol.

	Phase 1	Phase 2	Phase 3	Phase 4
Training Parameters	(Week 1-7)	(Week 8-14)	(Week 15-20)	(Week 21-40)
Session duration (min)	23.0	38.0	41.0	41.0
Effort time (min) ^a	6.66	16.5	24.0	24.0
Recovery time (min) ^b	16.34	21.5	17.0	17.0
Work-to-rest ratio	1:2	1:1	2:1	2:1
Work interval (sec)	20.0	30.0	40.0	40.0
Rest interval (sec)	40.0	30.0	20.0	20.0
Exercises amount	10	11	12	12
Rounds	2	3	3	3
Rest time/round (min)	3.0	2.5	2.5	2.0
Movement number ^c	Maximal	Maximal	Maximal	Maximal

^aEffort time = session duration – recovery time.

^bRecovery time = session duration – effort time.

^cMaximal number of movements during efforts time.

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Exercises amount	10	11	12	12
Rounds	2	3	3	3
Rest time/round (min)	3.0	2.5	2.5	2.0
Movement number ^c	Maximal	Maximal	Maximal	Maximal

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