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

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

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

Introduction

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

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

Regular exercise is an efficient tool for improving physical fitness, health and body composition in this population (1). Current exercise guidelines include progressive protocols of continuous endurance training (CET), resistance training (RT), or combined CET and RT training (CT) to induce cardiorespiratory, neuromuscular and metabolic adaptations (1). Structured RT is pivotal for preventing sarcopenia and osteoporosis in sedentary, premenopausal women with obesity through improvements in LBM and physical performance (21,40). High-intensity interval training (HIIT) is one of the most popular exercise modes (3) requiring less exercise volume compared to CET, RT, or CT and demonstrating high compliance rates when conducted under supervision in untrained individuals (34). HIIT includes repeated short-to-long bouts performed at an intensity that provokes a heart rate (HR) ≥80% of maximal hear rate (MHR) (39). The present, injury-free, hybrid-type exercise protocol integrates progressive HIIT and functional resistance accessory training into a circuit training format that has been shown to reduce body fat, increase LBM, RMR, endurance, exercise behavioural regulation and vitality with exceptional adherence rates in previously inactive women with obesity (4,6). Such an exercise approach incorporates endurance-based bodyweight drills and resistance-based alternative modalities (18) performed in a circuit, interval format and at moderate-to-high intensity adopting some of the principal characteristics of multimodal integrative neuromuscular training (44).

Although there is evidence that overweight or obese adults need comprehensive exercise strategies not only to reduce body mass and fat (1) but also to improve functional limitations while avoiding physical training–related injuries (37), there is a paucity of longitudinal studies to determine the efficacy of such a HIIT-type neuromuscular exercise approach on musculoskeletal fitness, mobility and bone health. Additionally, it is important to investigate potential changes in such physiological parameters, which result from the cessation of exercise, since exercise training is considered a fundamental component of every lifestyle intervention for this population. It has been observed an unfavorable effect of detraining on neuromuscular performance that was mainly influenced by the duration of training cessation, age, and training status (45). Characteristically, when an 8-month multicomponent exercise program performed by older overweight women was interrupted for only three months, musculoskeletal performance gains induced by previous training were abolished (49).

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

Materials and Methods

Study design

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

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

FIGURE 1 ABOUT HERE

Participants

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

TABLE 1 ABOUT HERE

Training

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

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

Measurements

Bone Health

Whole-body BMC and BMD were performed using a dual energy X-ray absorptiometry (DXA) scanner (GE Healthcare, Lunar DPX-NT) in the morning by the same experienced radiologist according to standard procedures (41). Briefly, participants were placed in a supine position with their body aligned along the central horizontal axis, their arms parallel to their body (without touching it), the forearms pronated, hands flat, legs fully extended, and feet secured using a velcro strap to prevent foot movement during the scan. The instrument was calibrated daily using a calibration epoxy resin phantom. All analyses were performed using the 12.2 GE enCORE software package.

Flexibility, Static Balance and Mobility

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

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

The Functional Movement Screening (FMS) with an ICC of >0.8 was used to evaluate functional mobility, postural stability and movement behavior in different settings (23). Two examiners (with an intra-rater reliability of 88.6%) performed this assessment. The FMS has been reported as a simple, quick, non-invasive and suitable movement-based assessment tool for middle-aged, overweight or obese aiming to evaluate their functional capacity levels (23). In brief, the FMS assesses seven fundamental movement tasks (deep squat, hurdle step, in-line lunge, active straight-leg raise, trunk stability push-up, rotary stability, shoulder mobility). Each movement task was scored from 0 to 3 points (0=pain with pattern regardless of quality, 1=unable to perform pattern, 2=able to perform pattern with compensation/imperfection, 3=able to perform pattern as directed) and their sum provided the total score ranging from 0 to 21 points (46).

Muscular Strength and Endurance

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

Statistical Analyses

A preliminary power analysis (effect size >0.55, probability error of 0.05, two-tailed alpha level, power of 0.9) using the G*Power 3.0.10 program based on the study design suggested that a sample of 36-40 participants was necessary to identify statistically meaningful trial effects. For all dependent variables, differences (for both “between” and “within” groups) of means (MD) and confidence intervals (CI) were calculated based on mixed models. Cohen’s *d* criteria were used to interpret the magnitude of MD as very small, small, medium, large, very large and huge for values 0.01, 0.20, 0.50, 0.80, 1.20 and 2.0, respectively. No assumptions were made for covariance matrices (unstructured) since repetitions were not that many to significantly reduce the degrees of freedom. All estimations were corrected based on the Bonferroni criterion for multiple comparisons. Results are presented as relative difference in time (Δ%). Since the variability of the change score in the intervention groups was greater than that in C, the response rate was analysed using the number of differential responders relative to the ratio of variance in TR and C groups providing multiple differential responder groups (10). Statistical significance was set at $p<0.05$. Data were analysed using the SPSS 22.0 software (IBM Corp., Armonk, NY, USA).

Results

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

Bone mineral density and bone mineral content

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

Flexibility, Static Balance and Mobility

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

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

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

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

Muscular strength

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

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

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

Muscular endurance

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

At post-training, TR exhibited greater changes of muscular endurance than C (curl-up: +103%/16.185–25.196/5.0/$p<0.001$; push-up: +195%/7.876–15.553/3.14/$p<0.001$; bodyweight squat: +136%/18.176–24.872/7.33/$p<0.001$) and TRD showed superior changes in muscular endurance than C (curl-up: +83%/12.185–21.196/3.27/$p<0.001$; push-up: +123%/3.590–11.267/1.99/$p<0.001$; bodyweight squat: +97%/11.961–8.658/4.66/$p<0.001$). TR had more favorable changes in muscular endurance relative to TRD (push-up: +32%/0.081–8.491/0.80/$p=0.044$; bodyweight squat: +20%/2.547–9.882/1.69/$p<0.001$). In TR, the response rate to all muscular endurance measures was 100% (Figure 3).

FIGURE 2 ABOUT HERE

TABLE 2 ABOUT HERE

FIGURE 3 ABOUT HERE

Discussion

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

This trial focused on physically inactive, middle-aged, overweight or obese who are characterized by increased cardiometabolic risk (11), poor functional capacity (32), a higher risk for musculoskeletal disorders (42) and physical limitations (19) compared to normoweight women. Overweight and obese adults are more prone to sustain injuries and exhibit knee osteoarthritis than individuals of a normal BMI (35). Hence, progressive, injury-free and effective exercise protocols are critical to reduce functional deficits that are responsible for a smaller PRoM in several joints (19), impaired quality of life and a rising prevalence of injuries in this population (17). In this study, a 10-month training program designed for inactive, overweight or obese women was injury-free and reported high adherence and low dropout rates. This outcome may support the necessity of prescribing progressive and supervised exercise regimens for this population aiming to promote a safe exercise experience that may be pivotal for behavioural regulation in exercise (4).

Bone adaptations

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

Flexibility, Static Balance and Mobility

Due to insufficient use of joints in inactive, overweight or obese individuals, the functional length of muscles' that cross these joints is reduced resulting in decreased PRoM (19). Hamstring and lower back flexibility improved by 40%, whereas PRoM in ankle, hip, shoulder, glenohumeral joints improved by 24-44% after 10 months of implementation. These adaptations were maintained after 5 months of detraining. These results coincide with a 10-38% increase in flexibility of inactive, overweight or obese older adults following long-term RT (13,14,15). These outcomes may be attributed to the features of the protocol, i.e. the incorporation of whole-body multiplanar movements mimicking ADLs. RT may promote flexibility if exercises are performed through a full range of motion to adequately activate both the agonist and antagonist muscle groups (15). Resistive exercises may not only increase muscle mass and contractility but they also improve the strength of tendons and ligaments thereby augmenting joints' PRoM (43). Studies employing compensatory overload models have shown a simultaneous elevation of muscle's strength and tendon's active fibroblast numbers, collagen synthesis and turnover rate (43). The strength of the junction between bone and ligament is also enhanced by this type of training (38). The association between body fat and flexibility performance changes in response to training supports the evidence that body composition may play some role in flexibility and mobility performance in overweight or obese adults (19).

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

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

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

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

Muscular performance adaptations

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

Detraining

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

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

Practical applications

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

Acknowledgments

The authors would like to express their appreciation for the outstanding efforts, positive attitude and impressive commitment of the participants.

Disclosure of interest

The authors report no conflict of interest.

References

1. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription* 10th ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2017.
2. American College of Sports Medicine. *ACSM's Health-Related Physical Fitness Assessment Manual* 5th ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins, 2017.
3. Batrakoulis, A. European survey of fitness trends for 2020. *ACSMs Health Fit J* 23: 28–35, 2019.
4. Batrakoulis, A, Loules, G, Georgakouli, K, et al. High-intensity interval neuromuscular training promotes exercise behavioral regulation, adherence and weight loss in inactive obese women. *Eur J Spor Sci* 2019. doi: 10.1080/17461391.2019.1663270. [Epub ahead of print]
5. Batrakoulis, A, Fatouros, IG, Jamurtas, et al. Dose-response effects of high-intensity interval neuromuscular exercise training on weight loss, performance, health and quality of life in inactive obese adults: Study rationale, design and methods of the DoIT trial. *Contemp Clin Trials Commun* 15:100386, 2019.
6. Batrakoulis, A, Jamurtas, AZ, Georgakouli, et al. High intensity, circuit-type integrated neuromuscular training alters energy balance and reduces body mass and fat in obese women: A 10-month training-detraining randomised controlled trial. *PLoS ONE* 13: e0202390, 2018.
7. Blue, MNM, Smith-Ryan, AE, Trexler, ET, Hirsch, KR. The Effects of High Intensity Interval Training on Muscle Size and Quality in Overweight and Obese Adults. *J Sci Med Sport* 21: 207-212, 2018.

8. Brown, CV, Neville, AL, Rhee, P, Salim, A, Velmahos, GC, Demetriades, D. The Impact of Obesity on the Outcomes of 1,153 Critically Injured Blunt Trauma Patients. *J Trauma* 59: 1048–1051, 2005.
9. Burgess, E, Hassmén, P, Welvaert, M, Pumpa, KL. Behavioural treatment strategies improve adherence to lifestyle intervention programmes in adults with obesity: a systematic review and meta-analysis. *Clin Obes* 7: 105–114, 2017.
10. Dankel, SJ, Loenneke, JP. A Method to Stop Analyzing Random Error and Start Analyzing Diferential Responders to Exercise. *Sports Med* 2019. doi: 10.1007/s40279-019-01147-0. [Epub ahead of print]
11. Do, K, Brown, RE, Wharton, S, Ardern, CI, Kuk, JL. Association between cardiorespiratory fitness and metabolic risk factors in a population with mild to severe obesity. *BMC Obes* 5, 2018.
12. Emaus, A, Veierod, MB, Furberg, AS, et al. Physical activity, heart rate, metabolic profile, and estradiol in premenopausal women. *Med Sci Sports Exerc* 40: 1022–1030, 2008.
13. Fatouros, IG, Kambas, A, Katrabasas, I, et al. Resistance training and detraining effects on flexibility performance in the elderly are intensity-dependent. *J Strength Cond Res* 20: 634–642, 2006.
14. Fatouros, IG, Kambas, A, Katrabasas, I, et al. Strength training and detraining effects on muscular strength, anaerobic power, and mobility of inactive older men are intensity dependent. *Br J Sports Med* 39: 776–780, 2005.
15. Fatouros, IG, Taxildaris, K, Tokmakidis, SP, et al. The Effects of strength training, cardiovascular training and their combination on flexibility of inactive older adults. *International Journal of Sports Medicine* 23: 112–119, 2002.
16. Freiberger, E, Häberle, L, Spirduso, WW, et al. Long-term effects of three multicomponent exercise interventions on physical performance and fall-related psychological outcomes in

community-dwelling older adults: A randomised controlled trial. *J Am Geriatr Soc* 60: 437–446, 2012.

17. Gua, JK, Charles, LE, Andrew, ME, Ma, CC, Hartley, et al. Prevalence of work-site injuries and relationship between obesity and injury among U.S. workers: NHIS 2004–2012. *J Safety Res* 58: 21–30, 2016.
18. Haff, GG, Beminger, D, Caulfield, S. Exercise Technique for Alternative Modes and Nontraditional Implement Training. In*: Essentials of Strength Training and Conditioning* 4th ed. G.G. Haff and N. Triplett, eds. Champaign: Human Kinetics, 2016. pp. 417–421.
19. Jeong, Y, Heo, S, Lee, G, Park, W. Pre-obesity and obesity impacts on passive joint range of motion. *Ergonomics* 61: 1223–1231, 2018.
20. Kell, RT, Bell, G, Quinney, A. Musculoskeletal Fitness, Health Outcomes and Quality of Life. *Sports Med* 31: 863–873, 2001.
21. Kelley, GA, Kelley, KS, Kohrt, WM. Exercise and bone mineral density in premenopausal women: A Meta-Analysis of Randomised Controlled Trials. *Int J Endocrinol* 2013: 741639, 2013.
22. King, M, Stanforth, D. The movement-based programming method for select populations. *ACSMs Health Fit J* 19: 17–22, 2014.
23. Kraus, K, Schütz, E, Taylor, WR, Doyscher, R. Efficacy of the Functional Movement Screen: A review. *J Strength Cond Res* 28: 3571–3584, 2014.
24. Lemmer, JT, Hurlbut, DE, Martel, GF, et al. Age and gender responses to strength training and detraining. *Med Sci Sports Exercise* 32: 1505–1512, 2000.
25. McRae, G, Payne, A, Zelt, JGE, Scribbans, TD, Jung, ME, et al. Extremely low volume, whole-body aerobic–resistance training improves aerobic fitness and muscular endurance in females. *Appl Physiol Nutr Metab* 37: 1124-1131, 2012.
26. Miller, BML, Brennan, L. Measuring and reporting attrition from obesity treatment programs: a call to action*! Obes Res Clin Pract* 9:187–202, 2015.

27. Bannister, R. *Brain's Clinical Neurology* 3th ed. New York, NY: Oxford University Press, 1969.

28. Myers, TR, Schneider, MG, Schmale, MS, Hazell, TJ. Whole-body aerobic resistance training circuit improves aerobic fitness and muscle strength in sedentary young females. *J Strength Cond Res* 29: 1592–1600, 2015.

29. NCD Risk Factor Collaboration. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *Lancet* 390: 2627–2642, 2017.

30. Agrawal, Y, Carey, JP, Hoffman, HJ, Sklare, DA, Schubert, MC. The modified Romberg balance test: normative data in US adults. *Otol Neurotol.* 2011; 32(8): 1309–1311.

31. Norkin, CC, White, DJ. *Measurement of Joint Motion: A Guide to Goniometry* 5th ed. Philadelphia, PA: F.A. Davis Company, 2016.

32. Pataky, Z, Armand, S, Müller-Pinget, S, Golay, A, Allet, L. Effects of obesity on functional capacity. *Obesity (Silver Spring)* 22: 56–62, 2014.

33. Perry, FT, Koehle, MS. Normative data for the functional movement screen in middle-aged adults. *J Strength Cond Res* 27: 458–462, 2013.

34. Roy, M, Williams, SM, Brown, et al. High-Intensity Interval Training in the Real World: Outcomes from a 12-Month Intervention in Overweight Adults. *Med Sci Sports Exerc* 50: 1818–1826, 2018.

35. Sabharwal, S, Root, MZ. Impact of obesity on orthopaedics. *J Bone Joint Surg Am* 94: 1045–1052, 2012.

36. Sperlich, B, Wallmann-Sperlich, B, Zinner, C, Von Stauffenberg, V, Losert, H, et al. Functional high-intensity circuit training improves body composition, peak oxygen uptake,

strength, and alters certain dimensions of quality of life in overweight women. *Front Physiol* 8: 172, 2017.

37. Savvidis, C., Tournis, S, Dede, AD. Obesity and bone metabolism. *Hormones* 17: 205–217, 2018.
38. Tipton, CM, Matthes, RD, Sandage, DS. In situ measurements of junction strength and ligament elongation in rats. *J Appl Physiol* 37: 758–761, 1974.
39. Türk, Y, Theel, W, Kasteleyn, MJ, et al. High intensity training in obesity: a Meta-analysis. *Obes Sci Pract* 3: 258–271, 2017.
40. Villareal, DT, Shah, K, Banks, MR, et al. Effect of weight loss and exercise therapy on bone metabolism and mass in obese older adults: a one-year randomised controlled trial. *J Clin Endocrinol Metab* 93: 2181–2187, 2008.
41. Vlachopoulos, D, Barker, AR, Ubago-Guisado, E, et al. Longitudinal Adaptations of Bone Mass, Geometry, and Metabolism in Adolescent Male Athletes: The PRO-BONE Study. *J Bone Miner Res* 32: 2269–2277, 2017.
42. Wearing, SC, Hennig, EM, Byrne, NM, et al. Musculoskeletal disorders associated with obesity: a biomechanical perspective. S. C. *Obesity Reviews* 7: 239–250, 2006.
43. Zamora, AJ, Marini, JF. Tendon and myotendinous junction in an overloaded skeletal muscle of the rat. *Anat Embryol* 179: 89–96, 1988.
44. Hewett, TE, Lindenfeld, TN, Riccobene, JV, Noyes, FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med* 27(6): 699–706, 1999.

45. Bosquet, L, Berryman, N, Dupuy, O, Mekary, S, Arvisais, D, Bherer, L, Mujika, I, Effect of training cessation on muscular performance: A meta-analysis. *Scand J Med Sci Sports* 23: e140–e149, 2013.

46. Cook, G, Burton, L, Hoogenboom, B. Pre-participation screening: The use of fundamental movements as an assessment of function—Part 1. *N Am J Sports Phys Ther* 1: 62–72, 2006.

47. Nuzzo, JL. The Case for Retiring Flexibility as a Major Component of Physical Fitness. *Sports Med* 2020; 50(5): 853–870.

48. Moghadasi, A, Ghasemi, G, Sadeghi-Demneh, E, Etemadifar, M. The effect of total body resistance exercise on mobility, proprioception and muscle strength of the knee in people with multiple sclerosis. *J Sport Rehabil* 2019 Apr 27: 1-8. doi: 10.1123/jsr.2018-0303.

49. Carvalho, MJ, Marques, E, Mota, J. Training and detraining effects on functional fitness after a multicomponent training in older women. *Gerontology* 2009; 55: 41–48.

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; PRoM, passive range of motion; FMS, functional movement screen; ^{1}for all groups (4-week adaptive period); ^{2}only for TR and TRD; ^{3}for 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; PRoM, passive range of motion; FMS, functional movement screen.

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

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

Alexios Batrakoulis[a], Panagiotis Tsimeas[a], Chariklia K. Deli[a], Dimitrios Vlachopoulos[b], Esther Ubago-Guisado[c], Athanasios Poulios[a], Athanasios Chatzinikolaou[d], Dimitrios Draganidis[a], Konstantinos Papanikolaou[a], Kalliopi Georgakouli[a], Dimitrios Batsilas[a], Luis Gracia-Marco[e], Athanasios Z. Jamurtas[a], Ioannis G. Fatouros[a]*

[a]*University of Thessaly, School of Physical Education and Sport Sciences, Karies, Trikala, Greece*

[b]*University of Exeter, College of Life and Environmental Sciences, Sport and Health Sciences, United Kingdom*

[c]*Universidad de Castilla-La Mancha, Health and Social Research Center, Cuenca, Spain*

[d]*Democritus University of Thrace, School of Physical Education and Sport Sciences, Komotini, Greece*

[e]*University of Granada, Faculty of Sport Sciences, Department of Physical Education and Sports, Granada, Spain*

*Corresponding author: Ioannis G. Fatouros, Exercise Biochemistry, Physiology and Nutrition Laboratory, School of Physical Education and Sport Sciences, University of Thessaly Trikala, 42100, Greece; Email: ifatouros@pe.uth.gr, telephone number: +30 24310 47047, fax number: +30 24310 47042

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

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

Introduction

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

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

Regular exercise is an efficient tool for improving physical fitness, health and body composition in this population (1). Current exercise guidelines include progressive protocols of continuous endurance training (CET), resistance training (RT), or combined CET and RT training (CT) to induce cardiorespiratory, neuromuscular and metabolic adaptations (1). Structured RT is pivotal for preventing sarcopenia and osteoporosis in sedentary, premenopausal women with obesity through improvements in LBM and physical performance (21,40). High-intensity interval training (HIIT) is one of the most popular exercise modes (3) requiring less exercise volume compared to CET, RT, or CT and demonstrating high compliance rates when conducted under supervision in untrained individuals (34). HIIT includes repeated short-to-long bouts performed at an intensity that provokes a heart rate (HR) ≥80% of maximal hear rate (MHR) (39). The present, injury-free, hybrid-type exercise protocol integrates progressive HIIT and functional resistance accessory training into a circuit training format that has been shown to reduce body fat, increase LBM, RMR, endurance, exercise behavioural regulation and vitality with exceptional adherence rates in previously inactive women with obesity (4,6). Such an exercise approach incorporates endurance-based bodyweight drills and resistance-based alternative modalities (18) performed in a circuit, interval format and at moderate-to-high intensity adopting some of the principal characteristics of multimodal integrative neuromuscular training (44).

Although there is evidence that overweight or obese adults need comprehensive exercise strategies not only to reduce body mass and fat (1) but also to improve functional limitations while avoiding physical training–related injuries (37), there is a paucity of longitudinal studies to determine the efficacy of such a HIIT-type neuromuscular exercise approach on musculoskeletal fitness, mobility and bone health. Additionally, it is important to investigate potential changes in such physiological parameters, which result from the cessation of exercise, since exercise training is considered a fundamental component of every lifestyle intervention for this population. It has been observed an unfavorable effect of detraining on neuromuscular performance that was mainly influenced by the duration of training cessation, age, and training status (45). Characteristically, when an 8-month multicomponent exercise program performed by older overweight women was interrupted for only three months, musculoskeletal performance gains induced by previous training were abolished (49).

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

Materials and Methods

Study design

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

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

FIGURE 1 ABOUT HERE

Participants

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

TABLE 1 ABOUT HERE

Training

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

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

Measurements

Bone Health

Whole-body BMC and BMD were performed using a dual energy X-ray absorptiometry (DXA) scanner (GE Healthcare, Lunar DPX-NT) in the morning by the same experienced radiologist according to standard procedures (41). Briefly, participants were placed in a supine position with their body aligned along the central horizontal axis, their arms parallel to their body (without touching it), the forearms pronated, hands flat, legs fully extended, and feet secured using a velcro strap to prevent foot movement during the scan. The instrument was calibrated daily using a calibration epoxy resin phantom. All analyses were performed using the 12.2 GE enCORE software package.

Flexibility, Static Balance and Mobility

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

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

The Functional Movement Screening (FMS) with an ICC of >0.8 was used to evaluate functional mobility, postural stability and movement behavior in different settings (23). Two examiners (with an intra-rater reliability of 88.6%) performed this assessment. The FMS has been reported as a simple, quick, non-invasive and suitable movement-based assessment tool for middle-aged, overweight or obese aiming to evaluate their functional capacity levels (23). In brief, the FMS assesses seven fundamental movement tasks (deep squat, hurdle step, in-line lunge, active straight-leg raise, trunk stability push-up, rotary stability, shoulder mobility). Each movement task was scored from 0 to 3 points (0=pain with pattern regardless of quality, 1=unable to perform pattern, 2=able to perform pattern with compensation/imperfection, 3=able to perform pattern as directed) and their sum provided the total score ranging from 0 to 21 points (46).

Muscular Strength and Endurance

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

Statistical Analyses

A preliminary power analysis (effect size >0.55, probability error of 0.05, two-tailed alpha level, power of 0.9) using the G*Power 3.0.10 program based on the study design suggested that a sample of 36-40 participants was necessary to identify statistically meaningful trial effects. For all dependent variables, differences (for both “between” and “within” groups) of means (MD) and confidence intervals (CI) were calculated based on mixed models. Cohen’s *d* criteria were used to interpret the magnitude of MD as very small, small, medium, large, very large and huge for values 0.01, 0.20, 0.50, 0.80, 1.20 and 2.0, respectively. No assumptions were made for covariance matrices (unstructured) since repetitions were not that many to significantly reduce the degrees of freedom. All estimations were corrected based on the Bonferroni criterion for multiple comparisons. Results are presented as relative difference in time (Δ%). Since the variability of the change score in the intervention groups was greater than that in C, the response rate was analysed using the number of differential responders relative to the ratio of variance in TR and C groups providing multiple differential responder groups (10). Statistical significance was set at $p<0.05$. Data were analysed using the SPSS 22.0 software (IBM Corp., Armonk, NY, USA).

Results

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

Bone mineral density and bone mineral content

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

Flexibility, Static Balance and Mobility

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

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

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

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

Muscular strength

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

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

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

Muscular endurance

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

At post-training, TR exhibited greater changes of muscular endurance than C (curl-up: +103%/16.185–25.196/5.0/$p<0.001$; push-up: +195%/7.876–15.553/3.14/$p<0.001$; bodyweight squat: +136%/18.176–24.872/7.33/$p<0.001$) and TRD showed superior changes in muscular endurance than C (curl-up: +83%/12.185–21.196/3.27/$p<0.001$; push-up: +123%/3.590–11.267/1.99/$p<0.001$; bodyweight squat: +97%/11.961–8.658/4.66/$p<0.001$). TR had more favorable changes in muscular endurance relative to TRD (push-up: +32%/0.081–8.491/0.80/$p=0.044$; bodyweight squat: +20%/2.547–9.882/1.69/$p<0.001$). In TR, the response rate to all muscular endurance measures was 100% (Figure 3).

FIGURE 2 ABOUT HERE

TABLE 2 ABOUT HERE

FIGURE 3 ABOUT HERE

Discussion

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

This trial focused on physically inactive, middle-aged, overweight or obese who are characterized by increased cardiometabolic risk (11), poor functional capacity (32), a higher risk for musculoskeletal disorders (42) and physical limitations (19) compared to normoweight women. Overweight and obese adults are more prone to sustain injuries and exhibit knee osteoarthritis than individuals of a normal BMI (35). Hence, progressive, injury-free and effective exercise protocols are critical to reduce functional deficits that are responsible for a smaller PRoM in several joints (19), impaired quality of life and a rising prevalence of injuries in this population (17). In this study, a 10-month training program designed for inactive, overweight or obese women was injury-free and reported high adherence and low dropout rates. This outcome may support the necessity of prescribing progressive and supervised exercise regimens for this population aiming to promote a safe exercise experience that may be pivotal for behavioural regulation in exercise (4).

Bone adaptations

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

Flexibility, Static Balance and Mobility

Due to insufficient use of joints in inactive, overweight or obese individuals, the functional length of muscles' that cross these joints is reduced resulting in decreased PRoM (19). Hamstring and lower back flexibility improved by 40%, whereas PRoM in ankle, hip, shoulder, glenohumeral joints improved by 24-44% after 10 months of implementation. These adaptations were maintained after 5 months of detraining. These results coincide with a 10-38% increase in flexibility of inactive, overweight or obese older adults following long-term RT (13,14,15). These outcomes may be attributed to the features of the protocol, i.e. the incorporation of whole-body multiplanar movements mimicking ADLs. RT may promote flexibility if exercises are performed through a full range of motion to adequately activate both the agonist and antagonist muscle groups (15). Resistive exercises may not only increase muscle mass and contractility but they also improve the strength of tendons and ligaments thereby augmenting joints' PRoM (43). Studies employing compensatory overload models have shown a simultaneous elevation of muscle's strength and tendon's active fibroblast numbers, collagen synthesis and turnover rate (43). The strength of the junction between bone and ligament is also enhanced by this type of training (38). The association between body fat and flexibility performance changes in response to training supports the evidence that body composition may play some role in flexibility and mobility performance in overweight or obese adults (19).

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

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

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

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

Muscular performance adaptations

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

Detraining

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

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

Practical applications

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

Acknowledgments

The authors would like to express their appreciation for the outstanding efforts, positive attitude and impressive commitment of the participants.

Disclosure of interest

The authors report no conflict of interest.

References

1. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription* 10th ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2017.
2. American College of Sports Medicine. *ACSM's Health-Related Physical Fitness Assessment Manual* 5th ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins, 2017.
3. Batrakoulis, A. European survey of fitness trends for 2020. *ACSMs Health Fit J* 23: 28–35, 2019.
4. Batrakoulis, A, Loules, G, Georgakouli, K, et al. High-intensity interval neuromuscular training promotes exercise behavioral regulation, adherence and weight loss in inactive obese women. *Eur J Spor Sci* 2019. doi: 10.1080/17461391.2019.1663270. [Epub ahead of print]
5. Batrakoulis, A, Fatouros, IG, Jamurtas, et al. Dose-response effects of high-intensity interval neuromuscular exercise training on weight loss, performance, health and quality of life in inactive obese adults: Study rationale, design and methods of the DoIT trial. *Contemp Clin Trials Commun* 15:100386, 2019.
6. Batrakoulis, A, Jamurtas, AZ, Georgakouli, et al. High intensity, circuit-type integrated neuromuscular training alters energy balance and reduces body mass and fat in obese women: A 10-month training-detraining randomised controlled trial. *PLoS ONE* 13: e0202390, 2018.
7. Blue, MNM, Smith-Ryan, AE, Trexler, ET, Hirsch, KR. The Effects of High Intensity Interval Training on Muscle Size and Quality in Overweight and Obese Adults. *J Sci Med Sport* 21: 207-212, 2018.

8. Brown, CV, Neville, AL, Rhee, P, Salim, A, Velmahos, GC, Demetriades, D. The Impact of Obesity on the Outcomes of 1,153 Critically Injured Blunt Trauma Patients. *J Trauma* 59: 1048–1051, 2005.

9. Burgess, E, Hassmén, P, Welvaert, M, Pumpa, KL. Behavioural treatment strategies improve adherence to lifestyle intervention programmes in adults with obesity: a systematic review and meta-analysis. *Clin Obes* 7: 105–114, 2017.

10. Dankel, SJ, Loenneke, JP. A Method to Stop Analyzing Random Error and Start Analyzing Diferential Responders to Exercise. *Sports Med* 2019. doi: 10.1007/s40279-019-01147-0. [Epub ahead of print]

11. Do, K, Brown, RE, Wharton, S, Ardern, CI, Kuk, JL. Association between cardiorespiratory fitness and metabolic risk factors in a population with mild to severe obesity. *BMC Obes* 5, 2018.

12. Emaus, A, Veierod, MB, Furberg, AS, et al. Physical activity, heart rate, metabolic profile, and estradiol in premenopausal women. *Med Sci Sports Exerc* 40: 1022–1030, 2008.

13. Fatouros, IG, Kambas, A, Katrabasas, I, et al. Resistance training and detraining effects on flexibility performance in the elderly are intensity-dependent. *J Strength Cond Res* 20: 634–642, 2006.

14. Fatouros, IG, Kambas, A, Katrabasas, I, et al. Strength training and detraining effects on muscular strength, anaerobic power, and mobility of inactive older men are intensity dependent. *Br J Sports Med* 39: 776–780, 2005.

15. Fatouros, IG, Taxildaris, K, Tokmakidis, SP, et al. The Effects of strength training, cardiovascular training and their combination on flexibility of inactive older adults. *International Journal of Sports Medicine* 23: 112–119, 2002.

16. Freiberger, E, Häberle, L, Spirduso, WW, et al. Long-term effects of three multicomponent exercise interventions on physical performance and fall-related psychological outcomes in

community-dwelling older adults: A randomised controlled trial. *J Am Geriatr Soc* 60: 437–446, 2012.

17. Gua, JK, Charles, LE, Andrew, ME, Ma, CC, Hartley, et al. Prevalence of work-site injuries and relationship between obesity and injury among U.S. workers: NHIS 2004–2012. *J Safety Res* 58: 21–30, 2016.
18. Haff, GG, Beminger, D, Caulfield, S. Exercise Technique for Alternative Modes and Nontraditional Implement Training. In*: Essentials of Strength Training and Conditioning* 4th ed. G.G. Haff and N. Triplett, eds. Champaign: Human Kinetics, 2016. pp. 417–421.
19. Jeong, Y, Heo, S, Lee, G, Park, W. Pre-obesity and obesity impacts on passive joint range of motion. *Ergonomics* 61: 1223–1231, 2018.
20. Kell, RT, Bell, G, Quinney, A. Musculoskeletal Fitness, Health Outcomes and Quality of Life. *Sports Med* 31: 863–873, 2001.
21. Kelley, GA, Kelley, KS, Kohrt, WM. Exercise and bone mineral density in premenopausal women: A Meta-Analysis of Randomised Controlled Trials. *Int J Endocrinol* 2013: 741639, 2013.
22. King, M, Stanforth, D. The movement-based programming method for select populations. *ACSMs Health Fit J* 19: 17–22, 2014.
23. Kraus, K, Schütz, E, Taylor, WR, Doyscher, R. Efficacy of the Functional Movement Screen: A review. *J Strength Cond Res* 28: 3571–3584, 2014.
24. Lemmer, JT, Hurlbut, DE, Martel, GF, et al. Age and gender responses to strength training and detraining. *Med Sci Sports Exercise* 32: 1505–1512, 2000.
25. McRae, G, Payne, A, Zelt, JGE, Scribbans, TD, Jung, ME, et al. Extremely low volume, whole-body aerobic–resistance training improves aerobic fitness and muscular endurance in females. *Appl Physiol Nutr Metab* 37: 1124-1131, 2012.
26. Miller, BML, Brennan, L. Measuring and reporting attrition from obesity treatment programs: a call to action*! Obes Res Clin Pract* 9:187–202, 2015.

27. Bannister, R. *Brain's Clinical Neurology* 3th ed. New York, NY: Oxford University Press, 1969.

28. Myers, TR, Schneider, MG, Schmale, MS, Hazell, TJ. Whole-body aerobic resistance training circuit improves aerobic fitness and muscle strength in sedentary young females. *J Strength Cond Res* 29: 1592–1600, 2015.

29. NCD Risk Factor Collaboration. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *Lancet* 390: 2627–2642, 2017.

30. Agrawal, Y, Carey, JP, Hoffman, HJ, Sklare, DA, Schubert, MC. The modified Romberg balance test: normative data in US adults. *Otol Neurotol.* 2011; 32(8): 1309–1311.

31. Norkin, CC, White, DJ. *Measurement of Joint Motion: A Guide to Goniometry* 5th ed. Philadelphia, PA: F.A. Davis Company, 2016.

32. Pataky, Z, Armand, S, Müller-Pinget, S, Golay, A, Allet, L. Effects of obesity on functional capacity. *Obesity (Silver Spring)* 22: 56–62, 2014.

33. Perry, FT, Koehle, MS. Normative data for the functional movement screen in middle-aged adults. *J Strength Cond Res* 27: 458–462, 2013.

34. Roy, M, Williams, SM, Brown, et al. High-Intensity Interval Training in the Real World: Outcomes from a 12-Month Intervention in Overweight Adults. *Med Sci Sports Exerc* 50: 1818–1826, 2018.

35. Sabharwal, S, Root, MZ. Impact of obesity on orthopaedics. *J Bone Joint Surg Am* 94: 1045–1052, 2012.

36. Sperlich, B, Wallmann-Sperlich, B, Zinner, C, Von Stauffenberg, V, Losert, H, et al. Functional high-intensity circuit training improves body composition, peak oxygen uptake,

strength, and alters certain dimensions of quality of life in overweight women. *Front Physiol* 8: 172, 2017.

37. Savvidis, C., Tournis, S, Dede, AD. Obesity and bone metabolism. *Hormones* 17: 205–217, 2018.
38. Tipton, CM, Matthes, RD, Sandage, DS. In situ measurements of junction strength and ligament elongation in rats. *J Appl Physiol* 37: 758–761, 1974.
39. Türk, Y, Theel, W, Kasteleyn, MJ, et al. High intensity training in obesity: a Meta-analysis. *Obes Sci Pract* 3: 258–271, 2017.
40. Villareal, DT, Shah, K, Banks, MR, et al. Effect of weight loss and exercise therapy on bone metabolism and mass in obese older adults: a one-year randomised controlled trial. *J Clin Endocrinol Metab* 93: 2181–2187, 2008.
41. Vlachopoulos, D, Barker, AR, Ubago-Guisado, E, et al. Longitudinal Adaptations of Bone Mass, Geometry, and Metabolism in Adolescent Male Athletes: The PRO-BONE Study. *J Bone Miner Res* 32: 2269–2277, 2017.
42. Wearing, SC, Hennig, EM, Byrne, NM, et al. Musculoskeletal disorders associated with obesity: a biomechanical perspective. S. C. *Obesity Reviews* 7: 239–250, 2006.
43. Zamora, AJ, Marini, JF. Tendon and myotendinous junction in an overloaded skeletal muscle of the rat. *Anat Embryol* 179: 89–96, 1988.
44. Hewett, TE, Lindenfeld, TN, Riccobene, JV, Noyes, FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med* 27(6): 699–706, 1999.

45. Bosquet, L, Berryman, N, Dupuy, O, Mekary, S, Arvisais, D, Bherer, L, Mujika, I, Effect of training cessation on muscular performance: A meta-analysis. *Scand J Med Sci Sports* 23: e140–e149, 2013.

46. Cook, G, Burton, L, Hoogenboom, B. Pre-participation screening: The use of fundamental movements as an assessment of function—Part 1. *N Am J Sports Phys Ther* 1: 62–72, 2006.

47. Nuzzo, JL. The Case for Retiring Flexibility as a Major Component of Physical Fitness. *Sports Med* 2020; 50(5): 853–870.

48. Moghadasi, A, Ghasemi, G, Sadeghi-Demneh, E, Etemadifar, M. The effect of total body resistance exercise on mobility, proprioception and muscle strength of the knee in people with multiple sclerosis. *J Sport Rehabil* 2019 Apr 27: 1-8. doi: 10.1123/jsr.2018-0303.

49. Carvalho, MJ, Marques, E, Mota, J. Training and detraining effects on functional fitness after a multicomponent training in older women. *Gerontology* 2009; 55: 41–48.

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; PRoM, passive range of motion; FMS, functional movement screen; [1]for all groups (4-week adaptive period); [2]only for TR and TRD; [3]for 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; PRoM, passive range of motion; FMS, functional movement screen.

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

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	36.4 ± 5.0	36.9 ± 4.3
	(30.0 – 44.0)	(30.0 – 45.0)	(30.0 – 45.0)
Body mass (kg)	80.2 ± 8.9	78.0 ± 9.9	78.7 ± 7.9
	(69.0 – 103.0)	(64.0 – 97.5)	(68.0 – 91.0)
Body height (m)	1.65 ± 0.5	1.66 ± 0.5	1.64 ± 0.6
	(1.55 – 1.75)	(1.60 – 1.77)	(1.55 – 1.76)
BMI ($kg \cdot m^{-2}$)	29.6 ± 3.0	28.2 ± 2.8	29.1 ± 3.0
	(27.0 – 33.6)	(25.9 – 34.3)	(26.9 – 31.5)
PA ($steps \cdot day^{-1}$)	6,400 ± 1,851	6,331 ± 1,042	6,870 ± 2,031
	(2,694 – 9,025)	(4,358 – 8,676)	(2,865 – 9,452)
Body fat (%)	46.7 ± 6.5	47.5 ± 3.2	46.2 ± 3.9
	(35.7 – 58.3)	(41.4 – 53.2)	(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.

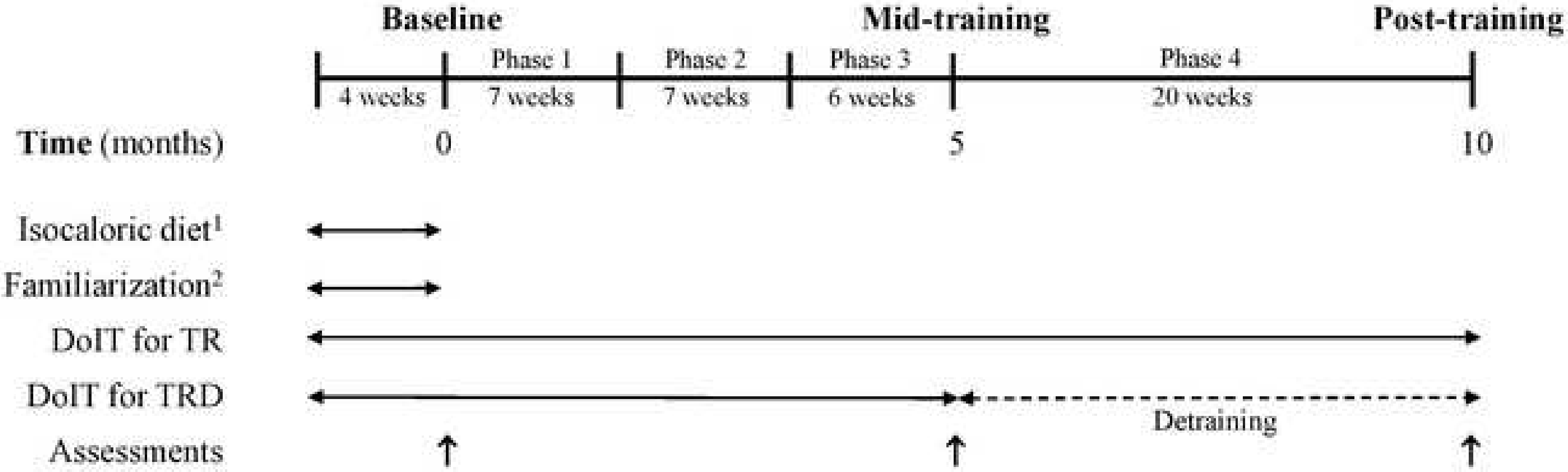
Table 2

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

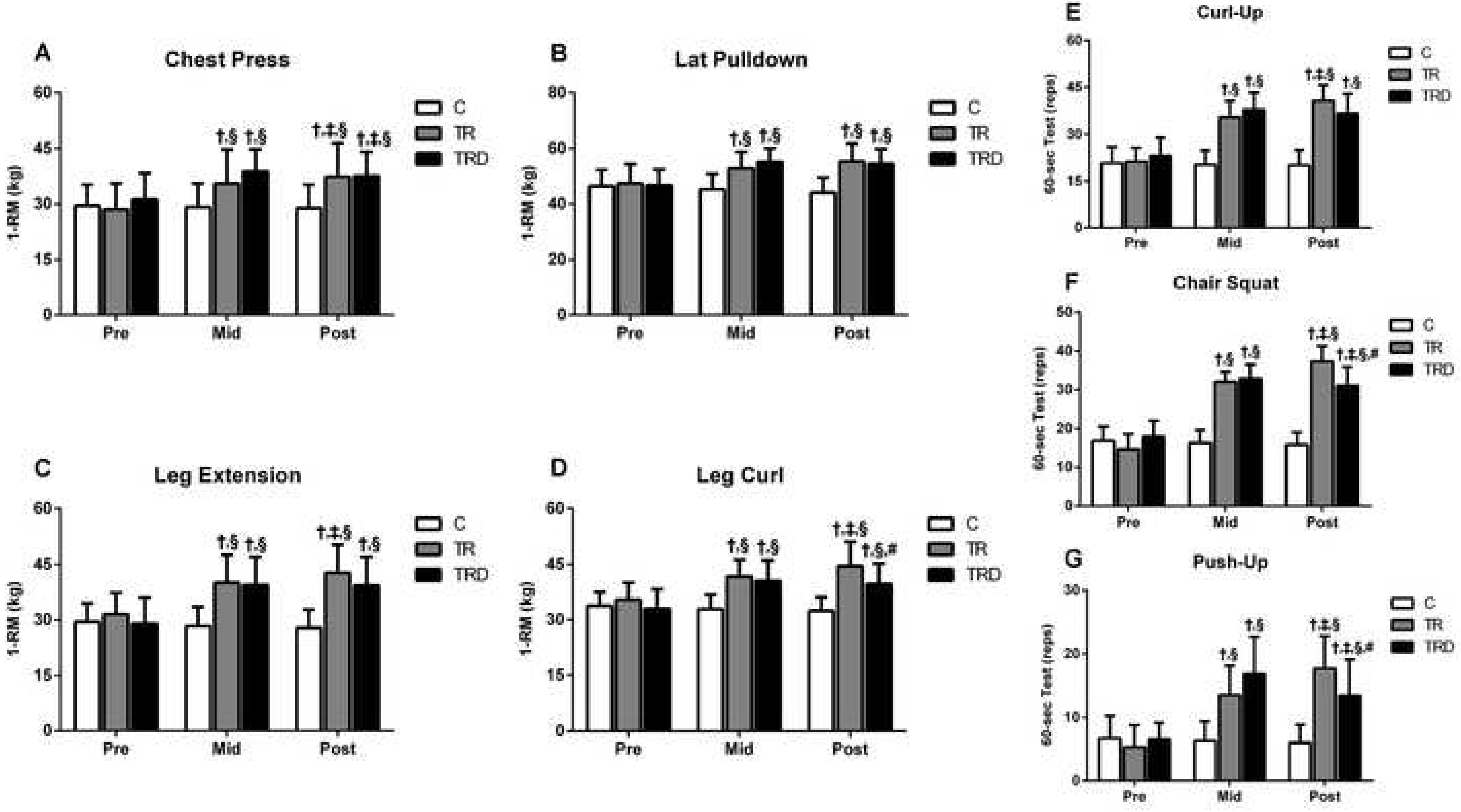
	C			**TR**			**TRD**		
Variables	**Pre**	**Mid**	**Post**	**Pre**	**Mid**	**Post**	**Pre**	**Mid**	**Post**
Modified sit and reach (cm)	27.3 ± 7.0	27.1 ± 6.7	27.0 ± 6.7	28.1 ± 6.5	37.3 ± 6.6 †,§	37.8 ± 6.9 †,‡,§	27.7 ± 8.1	36.4 ± 8.8 †,§	33.9 ± 8.6 †,‡,§
Ankle dorsiflexion (deg.)	12.0 ± 7.0	12.1 ± 6.9	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 $^{\dagger,\ddagger,\#}$
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 $^{\dagger,\ddagger,\S,\#}$
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, $p < 0.05$.

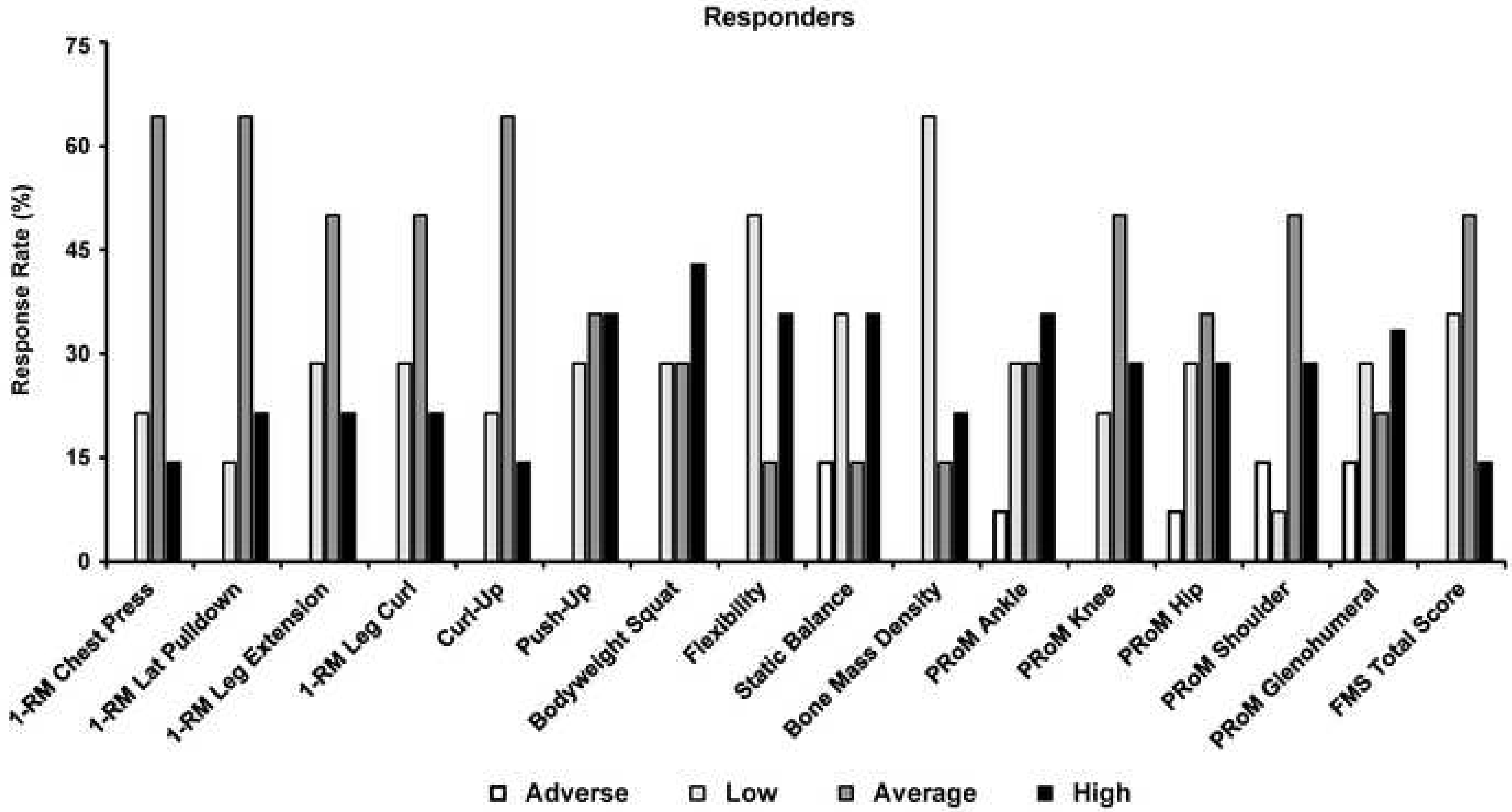
Figure


Baseline
Mid-training
Post-training
Phase 1
Phase 2
Phase 3
Phase 4
4 weeks
7 weeks
7 weeks
6 weeks
20 weeks
Time (months)
0
5
10
Isocaloric diet¹
Familiarization²
DoIT for TR
DoIT for TRD
Detraining
Assessments

Figure


A
Chest Press
1-RM (kg)
60
45
30
15
0
Pre
Mid
Post
†,§
†,§
†,‡,§
†,‡,§
C
TR
TRD
B
Lat Pulldown
1-RM (kg)
80
60
40
20
0
Pre
Mid
Post
†,§
†,§
†,§
†,§
C
TR
TRD
C
Leg Extension
1-RM (kg)
60
45
30
15
0
Pre
Mid
Post
†,§
†,§
†,‡,§
†,§
C
TR
TRD
D
Leg Curl
1-RM (kg)
60
45
30
15
0
Pre
Mid
Post
†,§
†,§
†,‡,§
†,§,#
C
TR
TRD
E
Curl-Up
60-sec Test (reps)
60
45
30
15
0
Pre
Mid
Post
†,§
†,§
†,‡,§
†,§
C
TR
TRD
F
Chair Squat
60-sec Test (reps)
50
40
30
20
10
0
Pre
Mid
Post
†,§
†,§
†,‡,§
†,‡,§,#
C
TR
TRD
G
Push-Up
60-sec Test (reps)
30
20
10
0
Pre
Mid
Post
†,§
†,§
†,‡,§
†,‡,§,#
C
TR
TRD

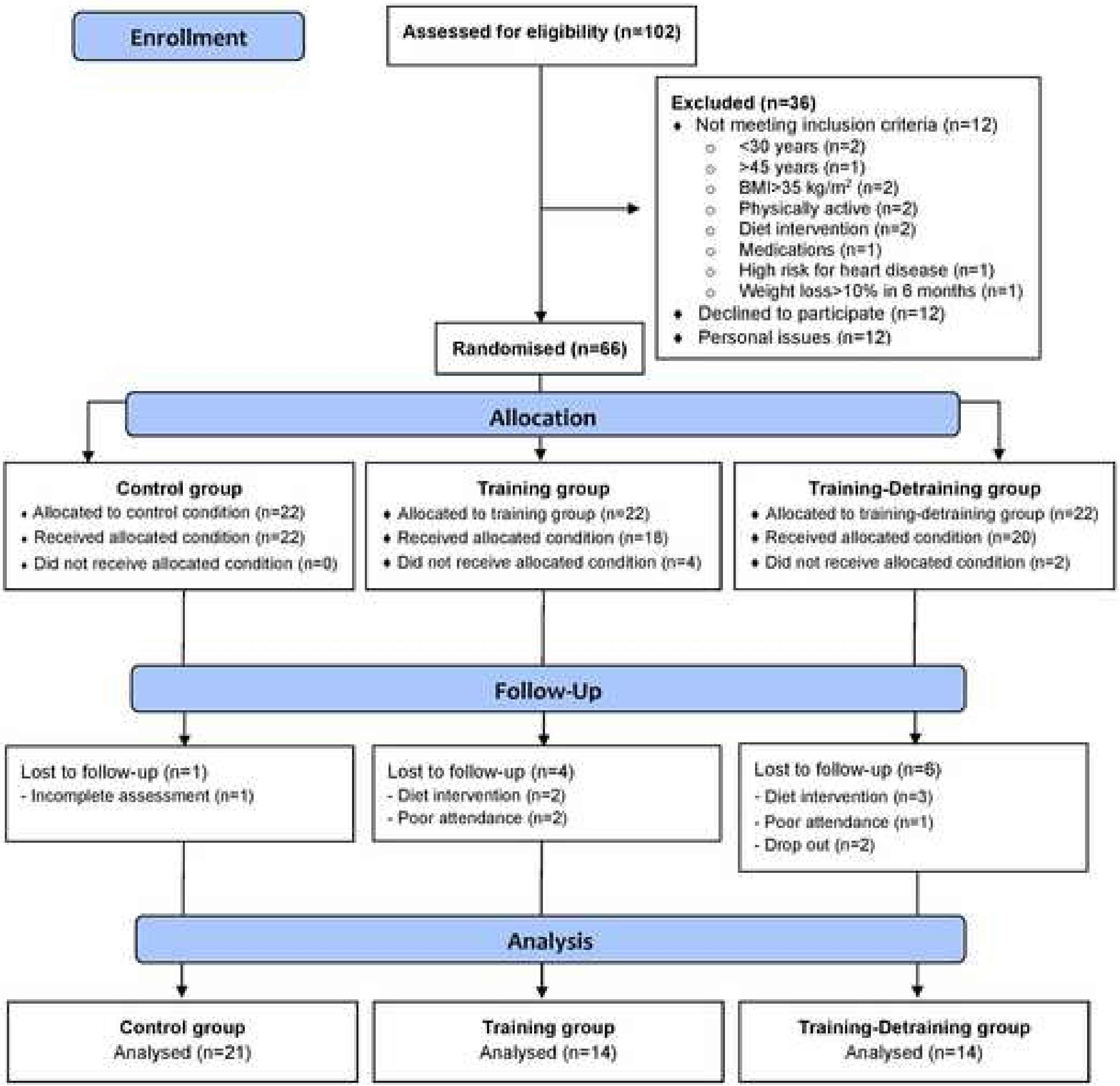
Figure


Responders
Response Rate (%)
75
60
45
30
15
0
1-RM Chest Press
1-RM Lat Pulldown
1-RM Leg Extension
1-RM Leg Curl
Curl-Up
Push-Up
Bodyweight Squat
Flexibility
Static Balance
Bone Mass Density
PRoM Ankle
PRoM Knee
PRoM Hip
PRoM Shoulder
PRoM Glenohumeral
FMS Total Score
Adverse
Low
Average
High

CONSORT

TRANSPARENT REPORTING of TRIALS

CONSORT 2010 Flow Diagram



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

	Exercises			
Adjunct Modalities	**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

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	36.4 ± 5.0	36.9 ± 4.3
	(30.0 – 44.0)	(30.0 – 45.0)	(30.0 – 45.0)
Body mass (kg)	80.2 ± 8.9	78.0 ± 9.9	78.7 ± 7.9
	(69.0 – 103.0)	(64.0 – 97.5)	(68.0 – 91.0)
Body height (m)	1.65 ± 0.5	1.66 ± 0.5	1.64 ± 0.6
	(1.55 – 1.75)	(1.60 – 1.77)	(1.55 – 1.76)
BMI ($kg \cdot m^{-2}$)	29.6 ± 3.0	28.2 ± 2.8	29.1 ± 3.0
	(27.0 – 33.6)	(25.9 – 34.3)	(26.9 – 31.5)
PA ($steps \cdot day^{-1}$)	6,400 ± 1,851	6,331 ± 1,042	6,870 ± 2,031
	(2,694 – 9,025)	(4,358 – 8,676)	(2,865 – 9,452)
Body fat (%)	46.7 ± 6.5	47.5 ± 3.2	46.2 ± 3.9
	(35.7 – 58.3)	(41.4 – 53.2)	(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.

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

	Exercises			
Adjunct Modalities	**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

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

Training Parameters	**Phase 1** **(Week 1-7)**	**Phase 2** **(Week 8-14)**	**Phase 3** **(Week 15-20)**	**Phase 4** **(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

[a] Effort time = session duration – recovery time.

[b] Recovery time = session duration – effort time.

[c] Maximal number of movements during efforts time.

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

Training Parameters	**Phase 1** **(Week 1-7)**	**Phase 2** **(Week 8-14)**	**Phase 3** **(Week 15-20)**	**Phase 4** **(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

[a] Effort time = session duration – recovery time.

[b] Recovery time = session duration – effort time.

[c] Maximal number of movements during efforts time.