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A Novel Low-Impact Resistance Exercise Program Increases Strength and Balance in Females Irrespective of Menopause Status

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BASIC SCIENCES

ABSTRACT

SVENSEN, E., C. P. KOSCIEN, N. ALAMDARI, B. T. WALL, and F. B. STEPHENS. A Novel Low-Impact Resistance Exercise Program Increases Strength and Balance in Females Irrespective of Menopause Status. *Med. Sci. Sports Exerc.*, Vol. 57, No. 3, pp. 501–513, 2025. **Introduction:** The reduction in sex hormone production across the menopause transition is thought to accelerate age-related decline in muscle mass, strength, and stability, increasing the risk of falls and fractures. We aimed to investigate whether a novel low-impact resistance exercise program could improve strength, balance, and body composition and whether any improvement was affected by menopause status. **Methods:** Seventy healthy, moderately active pre- (PRE; 46.7 ± (SD) 3.2 yr), peri- (PERI; 52.3 ± 2.2 yr), or post- (POST; 57.0 ± 2.5 yr) menopausal females, not taking hormone replacement therapy (HRT), were randomized to continue habitual physical activity (CON; n = 25) or complete a supervised resistance exercise program 4 d·wk^{-1} for 12 wk (EXC; n = 45). Strength at the hip and shoulder (isokinetic dynamometer), dynamic balance (Y-balance), flexibility (sit-and-reach and back-scratch), muscle thickness (rectus femoris, vastus intermedius (VI), and medial deltoid), and lean and % body fat (dual-energy x-ray absorptiometry) were measured before and after training. **Results:** Hip abduction and flexion peak torque (19% ± 48% and 20% ± 17%, respectively; P < 0.05), posterolateral and posteromedial balance (12% ± 15% and 13% ± 15%, respectively; P < 0.001), flexibility (21% ± 36%, P < 0.001), VI thickness (12% ± 19%, P = 0.032), and lean mass (2% ± 2%, P = 0.007) all increased over 12 wk in EXC, but not CON, with no difference in response between PRE, PERI, and POST. The changes in shoulder strength and body mass over 12 wk were not different between CON and EXC. **Conclusions:** This is the first study to demonstrate that the decline in sex hormones and an increase in age across the menopause transition do not affect the ability of lower limb (hip) strength and balance to adapt to a low-impact resistance exercise training program in females not taking HRT. **Key Words:** AGING, SKELETAL MUSCLE, ESTROGEN, FLEXIBILITY, PHYSICAL ACTIVITY

Skeletal muscle mass, strength, and quality naturally decline past the age of 40 yr. Females appear to be particularly susceptible to this decline during and after menopause, which is often attributed to a dramatic decline in sex hormone production (1–5). The decline in strength and/or hormone production in females between the ages of 40 and 60 yr is also associated with reduced balance, particularly in the lower limb hip flexor and abductor muscles (6–8). In combination, this ultimately increases the risk of falls and fractures later in life, particularly of the hip, leading to reduced quality of life and increased healthcare burden (9,10). Given that greater hip strength and lower body balance are associated with increased femoral neck bone mineral density and reduced incidence of falls (11,12), maintaining skeletal muscle strength and balance in aging females is vitally important, with a suitable time to intervene around menopause transition.

Detailed cross-sectional studies of premenopausal, perimenopausal, and postmenopausal females between 40 and 60 yr old suggest that the decline in lower limb strength and flexibility, but not balance (or upper limb strength), across the menopause transition may be prevented with increased physical activity (6,13). However, it is not known how the menopause transition affects the ability of hip strength and lower body balance to adapt to exercise training, in large part due to lack of intervention studies that include perimenopausal

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females or control for confounding factors such as the use of hormone replacement therapy (HRT). To our knowledge, only one study to date has compared the effect of resistance exercise training on muscle strength and mass in females across the menopause transition not using HRT. Isenmann et al. (14) demonstrated that twice-weekly, moderate-intensity "free weight" resistance exercise training for 10 wk increased muscle strength and thickness by around 50% and 5%, respectively, and by a similar amount in both premenopausal and postmenopausal females. However, the study did not include a control or perimenopausal group, and the postmenopausal group did not appear to gain muscle mass. Moreover, the resistance exercise training program was performed in a gym-based setting with specialist equipment, which may not be accessible or desirable for some people.

Low-impact body weight and resistance band exercise training programs that can easily be performed at home have been shown to be as effective at increasing muscle strength and mass in females as conventional resistance exercise training with free- and machine-weights (15). Importantly, simple body weight resistance exercises have been demonstrated to improve strength in females postmenopause (16,17) and balance in females between the ages of 40 and 60 yr (18), but comparisons of premenopausal, perimenopausal, and postmenopausal individuals were not made, and some participants were using HRT. Therefore, the aim of the present study was to investigate the temporal effect of a novel 12-wk dynamic low-impact body weight and resistance band exercise training program on muscle mass, strength, balance, and flexibility, with a focus on the lower limbs, in healthy females aged 40 to 60 yr precisely stratified into premenopausal, perimenopausal, and postmenopausal groups and matched for habitual physical activity. We hypothesized that perimenopausal and postmenopausal females with a decline in sex hormone production will have a reduced and/or delayed adaptation to the same exercise training program compared with premenopausal females.

METHODS

Participants. The study was conducted according to the guidelines laid out in the Declaration of Helsinki, and all procedures involving human participants were approved by the NHS Health Research Authority Research Ethics Committee (22/YH/0235). This study is part of a larger investigation registered at ClinicalTrials.gov (NCT05397418). Recruitment and data collection were carried out in the Nutritional Physiology Research Unit (NPRU) at the University of Exeter between March 2022 and October 2023.

Seventy-two healthy, moderately active females between the ages of 40 and 60 yr not currently or previously prescribed HRT, and residing in the southwest of England, volunteered to take part in the study. All individuals provided written informed consent at least 24 h after receiving verbal and written explanation of the experimental procedures. Participants' characteristics are shown in Table 1. Participants were deemed moderately active if they completed between 600 and 3000 $MET \cdot min \cdot wk^{-1}$ measured via the International Physical Activity Questionnaire (19). Exclusion criteria were as follows: 1) pregnant, lactating, or planning a pregnancy; 2) current diagnosis of a chronic disease such as diabetes, autoimmune disease, cardiovascular disease, kidney disease, or hypertension; 3) hysterectomy and/or ovariectomy; 4) current or recent, ≤6 months, or smoker; 5) currently taking medication or supplements that have been shown to impact muscle function and muscle mass in the last 6 months; 6) current or recent injury within the last 6 months that may affect the ability to carry out resistance exercise; 7) advised not to exercise by their general practitioner or medical professional; 8) resistance training consistently for 3 or more times per week for the last 2 months; and 9) a body mass index (BMI) <18 and >30 $kg \cdot m^{-2}$.

Participants were classified as pre- (PRE), peri- (PERI), or post- (POST) menopause based on baseline serum follicle-stimulating hormone (FSH) concentrations and menstrual cycle history as described in Bondarev et al. (1). Participants not using hormonal contraception medications were PRE if reporting regular menstrual cycle with FSH concentration less than 17 $IU \cdot L^{-1}$, PERI if reporting irregular menstrual cycle with FSH of 9.5 to 30 $IU \cdot L^{-1}$ or if occasional menstrual bleeding occurred during past 3 months even if FSH >30 $IU \cdot L^{-1}$, and POST if reporting no menstrual bleeding during the past 6 months with FSH >30 $IU \cdot L^{-1}$ or no menstrual bleeding had occurred during past 3 months and FSH >39 $IU \cdot L^{-1}$. If

TABLE 1. Baseline characteristics by PRE-(PRE), peri- (PERI), and post- (POST) menopause following randomization into 12 wk of habitual physical activity (CON, n = 25) or supervised low-impact resistance exercise (EXC, n = 45) intervention groups.

	CON			EXC			ANOVA		
	PRE	PERI	POST	PRE	PERI	POST	Menopause	Intervention	Intervention –menopause
n (%)	8 (32)	6 (24)	11 (44)	19 (42)	9 (20)	17 (37)			
Age (yr)	46.9 ± 2.1[a]	52.8 ± 1.6[b]	57.4 ± 1.7[a,b]	46.6 ± 3.5[a]	52.4 ± 1.8[b]	56.8 ± 2.8[a,b]	<0.001	0.843	0.939
Height (m)	1.6 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	1.7 ± 0.1	0.741	0.781	0.603
Body mass (kg)	64.9 ± 10.1	67.5 ± 6.1	65.5 ± 8.0	66.2 ± 7.5	68.9 ± 6.6	65.1 ± 8.3	0.951	0.875	0.752
BMI ($kg \cdot m^{-2}$)	24.1 ± 3.1	24.8 ± 1.9	24.6 ± 2.6	24.0 ± 1.8	25.5 ± 2.4	23.7 ± 2.1	0.529	0.997	0.913
Physical activity (MET·wk)	2663 ± 776	2689 ± 1175	3117 ± 468	2958 ± 1430	2812 ± 408	2901 ± 759	0.691	0.801	0.682
Dietary protein intake ($g \cdot d^{-1}$)	73.2 ± 21.5	65 ± 19.5	61.9 ± 11.9	73.0 ± 18.6	71.8 ± 13.2	71.2 ± 17.1	0.404	0.233	0.620
FSH ($IU \cdot L^{-1}$)[c]	5.1 ± 1.7[a]	59.7 ± 2 25.4[b]	78.6 ± 20.1[b]	6.9 ± 6.0[a]	49.7 ± 35.3[b]	88.7 ± 31.8[a,b]	<0.001	0.686	0.432
17β-Estradiol ($pmol \cdot L^{-1}$)[c]	408.1 ± 475.5	153.0 ± 151.2	22.5 ± 10.0[b]	451.2 ± 448.2	482.2 ± 584.6	96.3 ± 217.3[a,b]	<0.001	0.203	0.427
Progesterone ($nmol \cdot L^{-1}$)[c]	19.2 ± 21.8	1.2 ± 1.5[b]	0.3 ± 0.1[b]	15.0 ± 21.6	1.7 ± 2.3	0.5 ± 0.4[b]	<0.001	0.730	0.268

Values with units represent mean ± SD; significance set at $P < 0.05$.
[a] Significant difference from PERI.
[b] Significant difference from PRE.
[c] Raw values presented.

participants were using hormonal contraception medications, the categorization was based solely on FSH level and stricter cutoff values were applied (PRE: FSH <15 IU·L^{-1}, PERI: FSH 15–39 IU·L^{-1}, POST: FSH >39 IU·L^{-1}).

General study design. Following enrollment, participants were randomly assigned to either 12 wk of the exercise training intervention (EXC) or nontraining, habitual physical activity control (CON) group using covariate adaptive blocked randomization for age (40–44, 45–49, 50–54, 55+ yr) and BMI (<25, ≥25 kg·m^{-2}) by an external investigator (Fig. 1). The block randomization method was chosen to ensure an even distribution of premenopausal, perimenopausal, and postmenopausal females across the two intervention groups, without the need for additional blood samples for hormone analysis before randomization. In addition, participants were randomized to complete strength and muscle thickness measures on either the dominant or nondominant side, ensuring they were counterbalanced between groups.

The study protocol is outlined schematically in Figure 2. Before (WK0) and after 4 (WK4), 8 (WK8), and 12 (WK12) wk, participants arrived at the NPRU after an overnight fast to undergo a dual energy x-ray absorptiometry (DXA) scan. A venous blood sample was also taken at WK0 and WK12. Participants were then allowed standardized food and fluids before undergoing measures of muscle thickness, strength, dynamic balance, flexibility, body mass, and waist circumference.

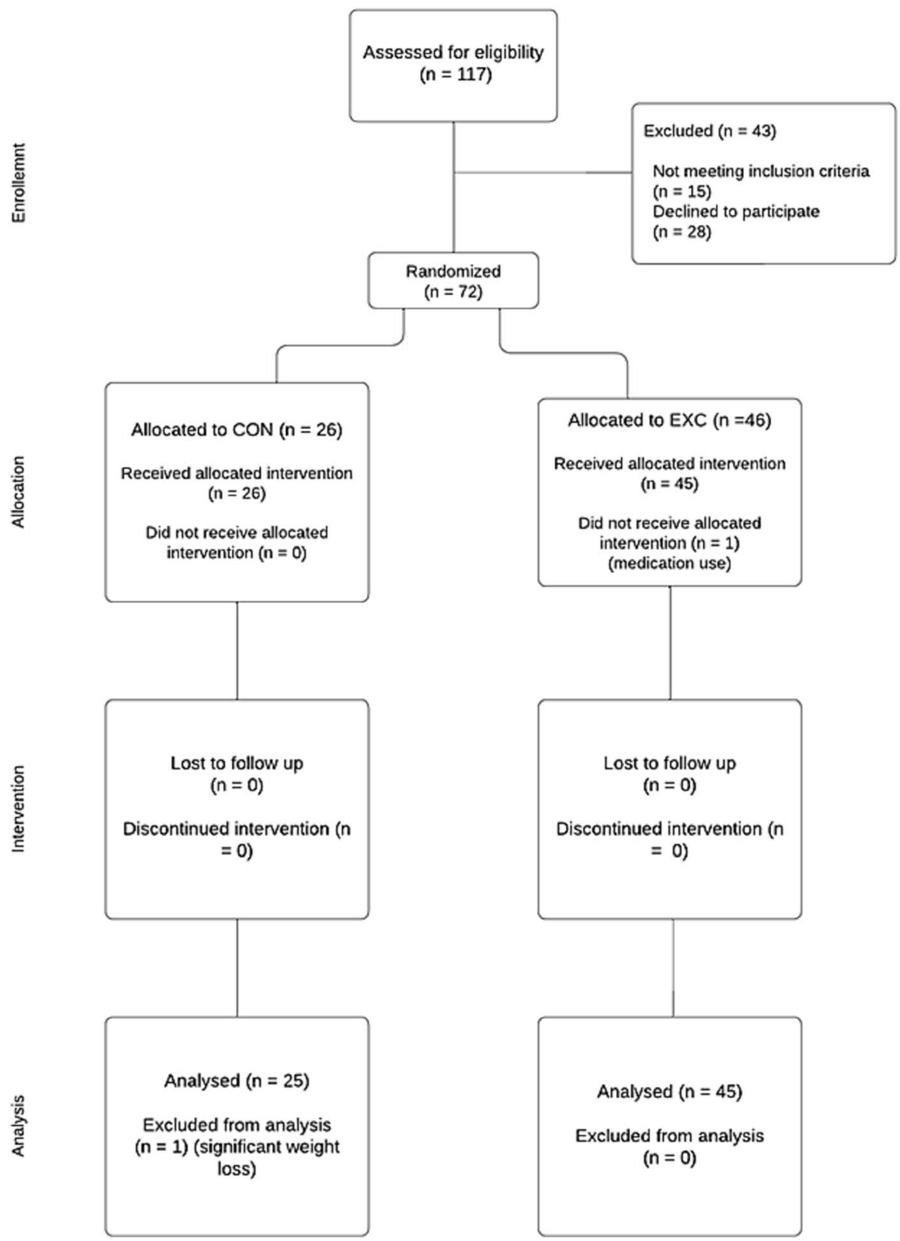

FIGURE 1—Consort diagram of study participant recruitment and allocation between 12 wk of supervised low-impact resistance exercise intervention (EXC) and habitual physical activity (CON) groups.

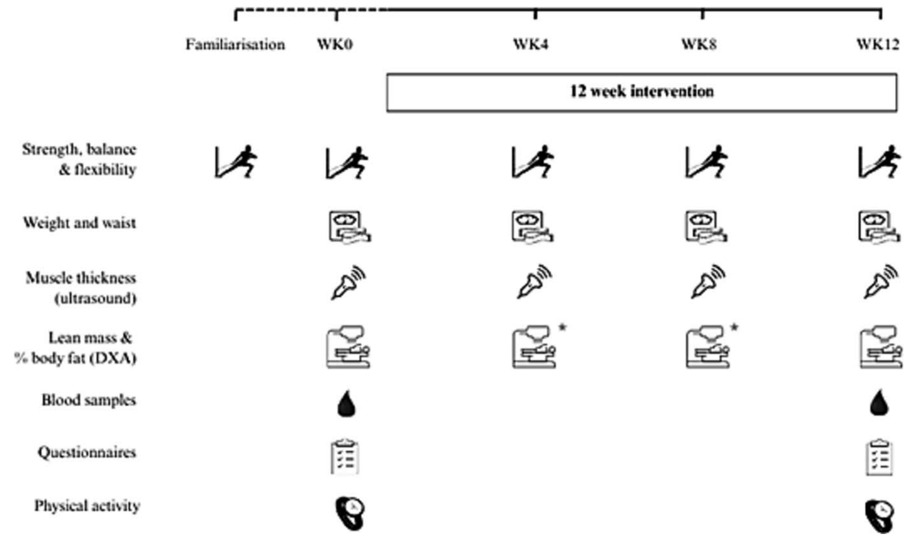

FIGURE 2—Graphical representation of the experimental protocol. Intervention of 12-wk supervised low-impact resistance exercise performed four times per week in the exercise group or habitual physical activity in control group. Strength of hip and shoulder abduction and flexion peak torque, balance, and flexibility were familiarized <2 wk before baseline (WK0) data collection. Strength, balance, and flexibility, as well as body composition measures of weight and waist, muscle thickness via ultrasound, and lean mass and % body fat from DXA, were collected at WK0 then at weeks 4 (WK4), 8 (WK8), and 12 (WK12). Blood samples collected for total cholesterol, total triglycerides, and HbA_{1c} analysis as well as questionnaires for quality of life (SF-36), sleep quality (PSQI), and enjoyment of exercise were collected at WK0 and WK12. Accelerometers recorded 7 d of physical activity during WK0 and WK12. *indicates measurement in the exercise group only at time point.

Participants completed a familiarization visit within 2 wk of the WK0 baseline testing. During the familiarization, participants performed each of the strength, dynamic balance and flexibility tests. Briefly, strength measures on the isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) were performed following verbal instruction and in the same order and number of repetitions as conducted during the measurement visits. The isokinetic dynamometer has been shown to have good retest for both shoulder (20) and hip (21). Participants performed the dynamic balance test (YBT Kit™, FysioSupplies B. V., Groningen, the Netherlands) following a visual demonstration and verbal instruction six times in each direction (22). In addition, participants practiced the flexibility tests as conducted during the visits. Questionnaires of quality of life, sleep quality, and enjoyment of exercise, as well as physical activity measurements were completed at WK0 and WK12. Physical activity was recorded for 7 d before the WK0 visit and again during WK12, by accelerometer (GENEactiv; Activinsights, Cambridgeshire, UK) worn continuously on the nondominant wrist, and converted to metabolic equivalents (MET) minutes (23). A 3-d food record (24) was recorded by participants while wearing the accelerometer before WK0 and during WK12 on two typical weekdays and one weekend day. Participants were provided with verbal and written instructions on how to complete the food record. Data were input and analyzed using online dietary analysis software (Nutritics v6, Dublin, Ireland).

Exercise intervention. Participants in EXC completed a proprietary (Pvolve, New York, NY) 12-wk whole-body, low-impact resistance training program four times a week. Exercise sessions were delivered via instructor lead videos and supervised by a member of the research team at the University of Exeter. Exercise sessions were scheduled early morning (7 AM), mid-morning (10 AM), and evening (6 PM). Participants were free to choose the time of day they attended. Participants were not advised on when to consume food before or after each session. Exercise classes were a combination of strength building movement using resistance bands at the hips, wrists, and ankle (Figs. 3A–D), and lifting hand weights (1–5 kg) and ankle weights (0.5–1.5 kg; Figs. 3E, F, H, I). Exercise classes also challenged postural control with weighted and unweighted movements, performing internal and external rotations of the hip (Figs. 3D, G) on one leg (Figs. 3F, I), as well as the use of equipment to challenge stability (Figs. 3F, I). In addition, body weight exercises of squats, lunges, and planks were incorporated into exercise classes. The program was progressive in nature, increasing in time from 2.7 h in week 1 to 3.3 h in WK12, corresponding to an average of 40 and 50 min per session, respectively. The intensity of the classes increased over the 12 wk with an increase in the number of movement repetitions and weight. From weeks 1 to 5, participants used a selection of 0.5- to 2-kg weights during exercise classes. These increased in weeks 6–12, with weights ranging from 1 to 5 kg. Participants were encouraged to select the greatest suggested weight for the exercise. In the event of failure, participants were instructed to decrease the weight and complete the number of repetitions.

The mean attendance of exercise classes in EXC intervention group was 98% ± 3%. In line with the exclusion criteria, no participants performed resistance training more than twice a week before intervention. Eighty-eight percent (n = 62) of participants reported not participating in structured resistance exercise. The remaining participants reported attending group exercise classes incorporating resistance exercise 1–2 times per month (n = 4) and 1–2 times per week (n = 4). The CON

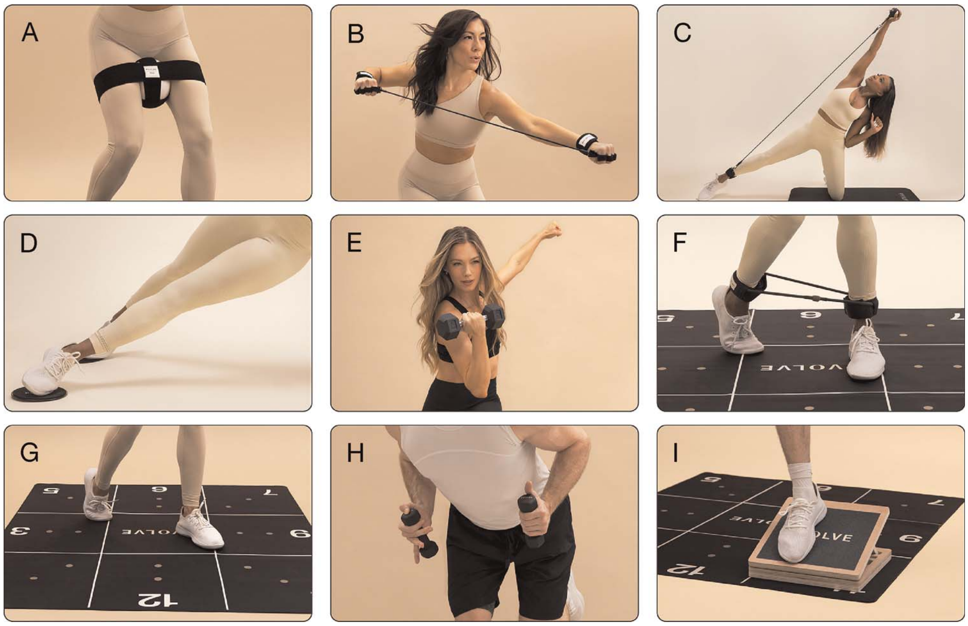

FIGURE 3—Low-impact resistance exercises utilizing resistance bands at the hip (A), arms (B, C), and ankle (C, D); hand weights (E, F, I); internal and external rotation of the hips (G, H); and challenges to postural stability (F, H, I).

condition was instructed to continue habitual physical activities, which met standard physical activity guidelines recommended by UK and US governments and leading health authorities of 150 min of moderate exercise per week. No changes in habitual activity were observed over the intervention period in CON as measured by accelerometer and paired-sample *t*-test (2929 ± 826 vs 2937 ± 810 MET·min, $P = 0.958$).

Strength. Hip and shoulder abduction and flexion, peak torque (PT) were measured using an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY). The participants were positioned according to the Biodex manual (Biodex Medical Systems 3) at the familiarization visit and for all subsequent visits. At each measurement visit, before testing, participants performed a warm-up on a stationary bike (Wattbike Atom; Wattbike Ltd, Nottingham, UK) for 10 min at 60–90 rpm, and on the dynamometer for three repetitions of 30%, 60%, and 90% effort. Thereafter, participants performed 2 × 5 repeats of maximal isokinetic contractions separated by 90 s of rest for each movement, with the highest value taken as PT. For the hip abduction test, participants laid on their side with range of motion set to 0°–45° and velocity at $30°·s^{-1}$. Hip flexion was performed supine with range of motion and velocity set to 0°–120° and $30°·s^{-1}$, respectively. Shoulder abduction and flexion were performed upright, with range of motion set at 0°–90° and velocity at $60°·s^{-1}$. Verbal encouragement was provided by the research investigator during each test.

Dynamic balance. Dynamic balance was measured using the lower quarter Y-balance test (LQ-YBT), a reliable measure of dynamic neuromuscular control and stability previously validated in females of 50 to 75 yr (25,26) in the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions. Briefly, at each visit, participants were instructed to stand barefoot on the central block of the YBT Kit™ (FysioSupplies B. V.), moving the reach indicator block as far away as possible in each direction with the nonstanding foot. Participants performed two practice trials followed by three test trials. During each trial, the standing heel remained flat on the central block with hands held at the hips, with each movement occurring in the same order (ANT > PM > PL). Trials were considered successful and recorded to the nearest half centimeter if the standing heel remained in contact with the central plate, hands remained positioned at the hips, and the participant successfully returned to the starting position without losing balance. If a test trial was deemed invalid, participants would repeat the trial with a maximum of six trial attempts permitted. Relative reach was calculated as the distance the reach indicator block was moved beyond the maximal upright reach distance relative to leg length [(reach distance − maximal upright reach)/leg length]. Maximal upright reach was the distance the reach indicator block was moved while the participant remained standing completely upright. This was calculated by applying a correction factor based on leg length for each direction (ANT, PL, PM). The correction factor was developed in a subset ($n = 31$) of participants (ANT 41% ± 3.7%; PL 62% ± 3.4%; PM 48% ± 6.4%). Leg length was measured in a supine position from the anterior superior iliac spine to medial malleolus and recorded to the nearest half centimeter (25). Intrarater coefficients of variation (CV) were ANT = 3.1%, PM = 2.8%, and PL = 2.6%, and interrater CV values were ANT = 2.0%, PM = 1.8%, and PL = 1.7%.

Flexibility. Flexibility of the hamstrings and lower back was conducted via a sit and reach test in accordance with the ACSM's health-related physical fitness assessment manual (27) using the sit and reach bench (Eveque Leisure Equipment

Ltd, Chesire, UK). Flexibility of the shoulder was conducted via a back scratch/zipper test (28). Before testing, participants were asked to complete a warm-up (arm rotations, leg swings, and feet touches) followed by two practice attempts and two maximum attempts. The best score of the two attempts was recorded and presented. For the sit and reach test, the interrater and intrarater CV values were 0.5% and 7.5%, respectively. For the back-scratch test, the interrater and intrarater CV values were 3.7% and 8.0%, respectively.

Body composition. Body mass (Seca digital column scale SEC-170, Hamburg, Germany) and waist circumference at the narrowest point were measured while standing in light clothing and without shoes. Muscle and subcutaneous fat thickness of the medial deltoid (MD), rectus femoris (RF), and vastus intermedius (VI) in the longitudinal and cross-sectional plane was acquired via a 7.7-Hz linear transducer, using B-mode ultrasonography (Vscan Air; GE Healthcare, Chalfont St Giles, UK). All images were collected by one investigator (E. S.) on the participants allocated testing side. Participants lay supine and were positioned according to the method described by Fischer et al. (29). Three images were acquired at each site and analyzed using ImageJ v1.53t (National Institutes of Health, Bethesda, MD) software after being scaled from pixels to cm. The intrarater CV values were 6.8%, 2.6%, and 2.6% for MD, RF, and VI, respectively,

A subset of participants (CON n = 17; EXC n = 24) completed whole-body DXA scan (E Lunar Prodigy Healthcare Corp., Madison, WI) in line with current recommendations (30). Scans were taken in standard mode, with participants supine, hands by their sides, and feet held ~10 cm apart. Lean mass (LM) and body fat percentage (BF) were calculated automatically using the DXA software (Lunar Prodigy, v14.10.022).

Blood sampling. Fasted venous blood samples were collected from the antecubital vein via venepuncture technique into two lithium heparin blood collection tubes (BD vacutainer LH; BD Diagnostics). The first tube was left to clot at room temperature for 30 min then centrifuged at 4000 rpm for 10 min at 4°C to obtain blood serum, which was then stored at −80°C. The second tube was immediately stored as whole blood at −20°C. Serum and whole blood samples were analyzed at an external laboratory by Exeter Clinical Laboratory International (Royal Devon and Exeter Hospital, Exeter, UK) for total triglycerides, total cholesterol, FSH, 17β-estradiol (E2), and progesterone on the on the Cobas 8000 automated platform (Roche Diagnostics, Rotkreuz, Switzerland). HbA_{1c} was analyzed using whole blood on the Capillarys 3 TERA instrument (Sebia, France).

Questionnaires. The three questionnaires were administered electronically. The Short Form Health Survey (SF-36) (31) is made up of 36 items, grouped into eight domains: physical functioning, physical role, bodily pain, general health, vitality, social functioning, emotional role, and mental health to assess QoL. The Pittsburgh Sleep Quality Index (PSQI) (32) is a reliable method to assesses sleep quality and sleep efficiency (33). Enjoyment of exercise was measured using the 10-item Groningen Enjoyment Questionnaire (GEQ) (34).

Data analyses. An initial *a priori* sample size of 56 participants was determined by assuming that resistance band training would increase lower body PT by 20% with a moderate effect size (D = 0.8) (35) (P < 0.05, power = 0.8; G*Power version 3.1.9.7). To accommodate for a 20% dropout rate, at least 72 participants would need to be recruited for the primary outcome of changes in strength. The power calculations were re-performed following the completion of the first 22 participants to provide an effect size estimate based on our primary aim to detect differences with training between menopause status (PRE, PERI, and POST). The resultant sample size was 48 total subjects, based on repeated-measures ANOVA within-between interactions with a medium effect (f) (0.25), P < 0.05, and a power of 0.8 ($1 - \beta$ error), based on the six-arm model and four repeated measurements (24 participants per intervention group, distributed across menopause status). In addition, due to the later introduction of DXA measurements in order to determine changes in lean mass and % body fat change with training, ethical implications required a power analysis assuming a 5% increase in lean mass (36), and a 2:1 ratio of EXC to CON (given little benefit of intervention to control group), determined an additional 22 participants were required in the EXC group (P < 0.05, power = 0.8; G*Power version 3.1.9.7). Thus, accounting for a lower than expected dropout rate, the participant randomization was revised to n = 26 in CON and n = 46 in EXC.

Baseline differences between groups were determined using a two-way ANOVA, with intervention (CON and EXC) and menopause (PRE, PERI, and POST) groups as between factors. E2 and progesterone values were not normally distributed and log transformed for analysis. Pearson chi-square test was performed to determine distribution of menopause groups across CON and EXC at baseline. A three-way repeated-measures ANOVA was used to detect changes in all outcome measures between intervention (CON and EXC) and/or menopause group (PRE, PERI, and POST) over the intervention period (time). Time was WK0, WK4, WK8 and WK12, or WK0 and WK12 dependent on measurement frequency (Fig. 1). In the event of differences being detected between intervention groups for DXA outcomes from WK0 to WK12, a further analysis of EXC using a mixed two-way ANOVA (menopause–time) was performed to identify any menopause group differences. For all ANOVAs, when significant interactions or main effects were observed, Bonferroni *post hoc* tests were performed. The Greenhouse–Geisser correction was applied if sphericity was violated. Missing data were handled using expected-maximization algorithm for minimal (<5%) missing data points; otherwise, participant data for that outcome were excluded. Statistical analysis was completed using SPSS statistical software (SPSS for Windows version 28.0.1.0, IBM), and graphs were constructed using GraphPad Prism software (Graphpad version 10.1.0, GraphPad Software). Statistical significance was set at P < 0.05. All data are presented as mean ± SD, unless otherwise stated.

RESULTS

Seventy-two participants were randomized to either control (CON; n = 26) or exercise (EXC; n = 46) intervention group.

One participant from CON was excluded from analysis due to significant weight loss (3.4% body weight) during the intervention period, and one participant in EXC discontinued the intervention due to medication use. Attendance rates in EXC during the 12-wk resistance exercise program were 98.0% ± 3.0%, with no difference between menopause groups (P = 0.606, data not shown).

Participant characteristics. Baseline characteristics (height, body mass, BMI, habitual physical activity, dietary protein intake) were comparable among the intervention groups (P = 0.781, P = 0.875, P = 0.997, P = 0.801, P = 0.233, respectively; Table 1). As expected, differences were detected between menopause groups ($P < 0.05$) for age, FSH, E2, and progesterone. PRE participants were younger with lower circulating FSH than PERI, and PERI participants were younger with lower circulating FSH than POST (Table 1). However, within CON, there was no significant difference in FSH between PERI and POST (P = 0.924). Serum E2 and progesterone were higher in PRE compared with POST in both CON and EXC intervention groups. PERI had higher serum E2 concentrations than POST in EXC group only, and within the CON group, progesterone levels were significantly lower in PERI than PRE (Table 1). There were no differences between intervention groups of PRE, PERI, and POST menopause participants ($\chi^2(2) \geq 0.711$, P = 0.701). No changes in habitual activity were observed over the intervention period in CON as measured by accelerometer (2929 ± 826 vs 2937 ± 810 MET·min; paired-sample t-test, P = 0.958). No changes in physical activity or protein intake were detected between intervention (time–intervention, P = 0.678 and P = 0.890, respectively) and menopause groups (time–intervention–menopause, P = 0.119 and P = 0.832, respectively) over the intervention period (data not shown).

Strength. Hip abduction PT (Fig. 4A) did not change over 12 wk in CON (96.6 ± 25.4 to 95.5 ± 26.3 N·m·kg^{-1}; $P > 0.05$), whereas hip abduction PT increased over the 12-wk intervention period by 19% ± 48% in EXC (time–intervention, P = 0.031) from a comparable baseline (Supplemental Table 1, Supplemental Digital Content, http://links.lww.com/MSS/D118). The increases in hip abduction PT in the EXC intervention group were regardless of menopause status (time–intervention–menopause, P = 0.171). Hip flexion PT (Fig. 4B) did not change in CON (105.1 ± 27.1 to 100.0 ± 23.6 N·m·kg^{-1}; $P > 0.05$) but, from a comparable baseline (99.0 ± 22.1 N·m·kg^{-1}), progressively increased across all menopause groups over the intervention by 20% ± 17% in EXC (time–exercise effect, $P < 0.001$; Supplemental Table 1, Supplemental Digital Content, http://links.lww.com/MSS/D118).

No change by intervention ($P > 0.05$) was observed in shoulder abduction (Fig. 4C) or flexion PT (Fig. 4D). However, shoulder abduction PT increased in both EXC and CON from WK0 (35.8 ± 8.8 N·m·kg^{-1}) at WK4 (38.3 ± 10.6 N·m·kg^{-1}, P = 0.011) and WK12 (39.7 ± 10.4 N·m·kg^{-1}, P = 0.006). Similarly, shoulder flexion PT increased ($P < 0.001$) from WK0 (36.3 ± 10.45 N·m·kg^{-1}) at each time point, WK4 (40.3 ± 12.85 N·m·kg^{-1}, P = 0.011), WK8 (40.6 ± 13.15 N·m·kg^{-1}, P = 0.004), and WK12 (42.4 ± 15.45 N·m·kg^{-1}, P = 0.004), irrespective of intervention group. An effect of menopause over the intervention period was observed in shoulder abduction PT (time–menopause, P = 0.016), with PT increasing in POST at WK12 (39.7 ± 12.5 N·m·kg^{-1}) from WK0 (33.7 ± 9.5 N·m·kg^{-1}, $P < 0.001$) and WK4 (35.4 ± 9.85 N·m·kg^{-1}, P = 0.013). No effect of menopause over the intervention period (time–menopause, P = 0.338) was observed in shoulder flexion PT (Supplemental Table 1, Supplemental Digital Content, http://links.lww.com/MSS/D118).

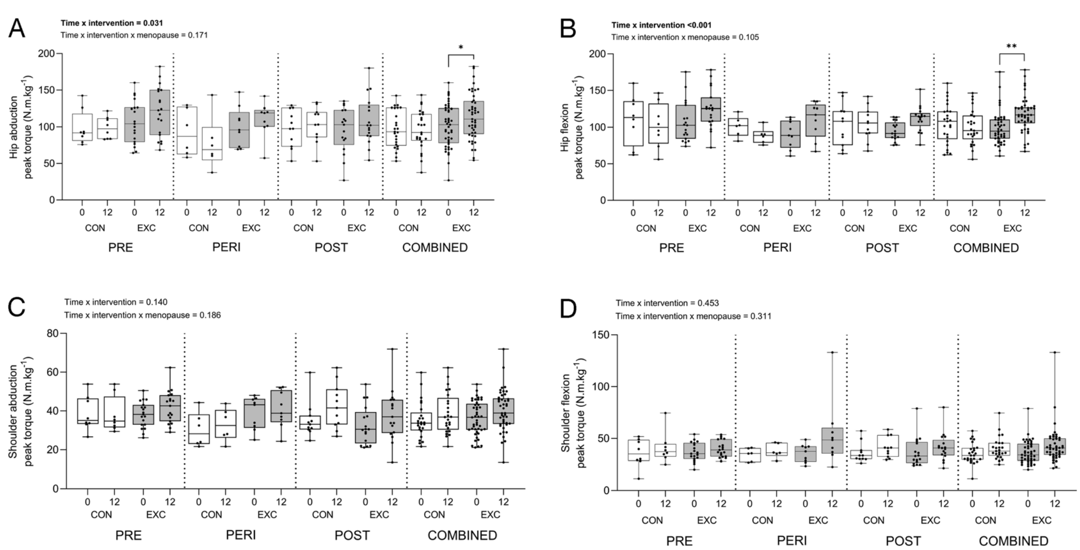

FIGURE 4—Hip abduction (A), hip flexion (B), shoulder abduction (C), and shoulder flexion (D) peak torque before (0) and after 12 wk (12) of habitual physical activity (CON, n = 25) or a supervised low-impact resistance training program (EXC, n = 45). Data were analyzed with repeated-measures ANOVA between EXC and CON intervention groups (COMBINED) and within healthy pre- (PRE), peri- (PERI), and post- (POST) menopausal females. Data were analyzed with repeated-measures ANOVA. Values are mean ± SD. * represents a significant difference from 0, $P < 0.05$; ** represents a significant difference from 0, $P < 0.001$.

Dynamic balance and flexibility. ANT reach did not change during the CON intervention period (21% ± 4% to 22% ± 3%, P = 0.308; Fig. 5A). However, differences were detected within EXC by the menopause group (intervention–menopause–time, P < 0.001), with no change in ANT reach in EXC PRE (23% ± 4% to 23% ± 4%, P > 0.05), an increase in EXC POST by 12% ± 13% from WK0 to WK8 (21% ± 4% to 23% ± 4%, P = 0.003), and a decline in EXC PERI from WK4 to WK12 (21% ± 3% to 19% ± 5%, P = 0.015). This decline resulted in a greater reach in EXC PRE than EXC PERI at WK12 (23 ± 4 vs 19 ± 5, respectively; P = 0.024; Fig. 5A). During the intervention period in CON, PL reach did not change (41% ± 8% to 42% ± 8%, P > 0.05), but PM reach increased by WK8 from WK0 (52% ± 9% to 54% ± 8%, P = 0.022). On the other hand, PL reach increased by 12% ± 15% in EXC from WK0 (40% ± 8%) at WK8 (43 ± 7%, P = 0.002) and WK12 (44 ± 6%, P < 0.001; Fig. 5B), and PM reach progressively increased in EXC by 13% ± 15% from baseline 50% ± 9% to 53% ± 8% (P < 0.001), 54% ± 8% (P < 0.001), and 56% ± 7% (P < 0.001) at WK4, WK8, and WK12, respectively (Fig. 5C). No effect of menopause was detected in either PL or PM reach.

Sit and reach distance (Fig. 5D) did not change over the intervention period in CON (23.9 ± 8.5 to 24.1 ± 8.2 cm; P > 0.05) but increased across all menopause groups in EXC (time–intervention effect, P = 0.021) from WK0 (21.0 ± 8.3 cm) by 17% ± 32% at WK4 (23.4 ± 7.6 cm, P < 0.001) and remained elevated during the intervention (WK8, 22.9 ± 7.5 cm, P = 0.004; WK12, 23.4 ± 7.3 cm, P < 0.001) resulting in a 21% ± 36% increase. Back scratch test scores (Supplemental Table 2, Supplemental Digital Content, http://links.lww.com/MSS/D118) did not change at any time point between intervention conditions and menopause group (all P > 0.05).

Body composition. Body mass, waist circumference, and body fat percentage (Table 2) did not change in either EXC or CON over the course of the intervention (all P > 0.05). Lean mass did not change in CON (40.0 ± 3.4 to 40.0 ± 3.7 kg; P > 0.05), but increased in EXC by 2% ± 2%, with a mean increase of 0.79 ± 0.86 kg (range, −0.55 to 2.27 kg) from WK0 to WK12 (P = 0.007; Table 2) but no difference between menopause groups (P = 0.847). Muscle thickness and subcutaneous fat (Table 2) of the medial deltoid and rectus femoris, in the cross-sectional and longitudinal plane, did not change over time between intervention conditions and menopause groups (all P > 0.05). Muscle thickness of the vastus intermedius did not change over the intervention period in the longitudinal plane (Table 2), but increased in the cross-sectional plane in EXC from WK0 at WK4 (P = 0.002) and WK12 (P = 0.005; Table 2).

Blood sampling. Serum total cholesterol (Supplemental Table 3, Supplemental Digital Content, http://links.lww.com/MSS/D118) did not change during the intervention period in CON (5.2 ± 1.0 to 5.2 ± 0.8 mmol·L^{-1}; P > 0.05), EXC PRE (5.2 ± 1.0 to 5.2 ± 1.0 mmol·L^{-1}; P > 0.05), or EXC POST (6.0 ± 0.9 to 6.2 ± 0.9 mmol·L^{-1}), but EXC PERI decreased from 6.5 ± 1.7 at WK0 to 5.6 ± 0.8 mmol·L^{-1} at WK12 (P < 0.001). Serum triglycerides and whole blood HbA_{1c} levels did not change at either time point between intervention

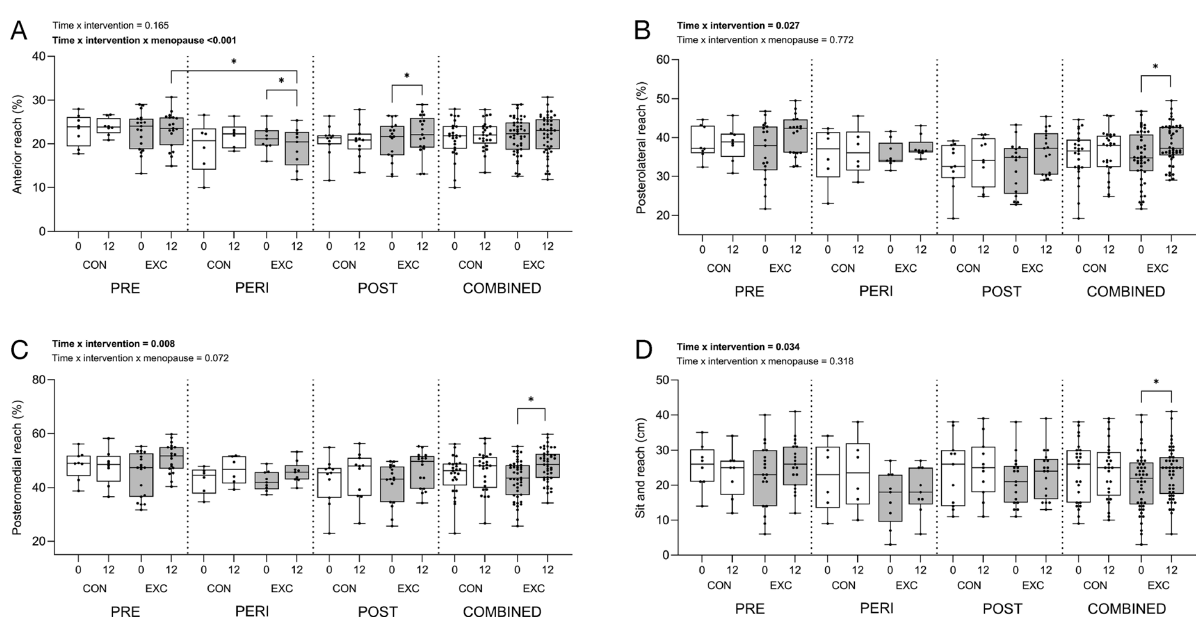

FIGURE 5—Anterior (A), posterolateral (B), posteromedial (C), and sit and reach (D) reach score (cm) before (0) and after 12 wk of habitual physical activity (CON, n = 25) or a supervised low-impact resistance training program (EXC, n = 45). Data were analyzed with repeated-measures ANOVA between EXC and CON intervention groups (COMBINED) and within healthy pre- (PRE), peri- (PERI), and post- (POST) menopausal females. Values are mean ± SD. * represents a significant difference from 0, P < 0.05; # represents a significant difference within the intervention group between the menopause groups, P < 0.05.

TABLE 2. Weight, waist, muscle thickness, and subcutaneous fat of the medial deltoid, rectus femoris, and vastus intermedius in the cross section and longitudinal plane during 12 wk of habitual physical activity (CON, n = 25) or a supervised low-impact resistance training program (EXC, n = 45) in pre- (PRE), peri- (PERI), and post- (POST) menopausal females.

	Week 0		Week 4		Week 8		Week 12	
	CON	EXC	CON	EXC	CON	EXC	CON	EXC
Weight (kg)								
PRE	64.9 ± 10.8	66.8 ± 6.6	65.4 ± 10.9	67.0 ± 6.5	65.8 ± 11.3	67.1 ± 6.3	65.3 ± 11.5	66.9 ± 6.3
PERI	67.5 ± 6.7	65.5 ± 8.5	66.8 ± 7.1	65.5 ± 8.5	67.1 ± 7.3	65.1 ± 8.4	67.3 ± 8.1	65.9 ± 8.7
POST	65.1 ± 8.7	66.2 ± 7.8	65.4 ± 8.9	66.1 ± 7.8	65.1 ± 8.8	66.1 ± 7.8	64.7 ± 8.9	65.7 ± 8.2
Combined	65.6 ± 8.7	66.3 ± 7.3	65.8 ± 8.9	66.4 ± 7.3	65.8 ± 9.0	66.3 ± 7.3	65.5 ± 9.3	66.2 ± 7.4
Waist (cm)								
PRE	72.4 ± 4.1	74.2 ± 5.3	75.0 ± 5.6	76.2 ± 5.8	74.3 ± 5.0	76.3 ± 5.8	72.2 ± 6.5	74.5 ± 5.1
PERI	76.9 ± 6.3	75.2 ± 8.1	76.6 ± 6.5	75.0 ± 7.4	75.6 ± 5.3	75.5 ± 7.0	75.6 ± 8.2	74.8 ± 8.0
POST	74.8 ± 5.7	74.9 ± 6.5	75.7 ± 6.5	75.7 ± 8.0	74.7 ± 5.0	76.0 ± 7.0	73.9 ± 6.5	74.6 ± 8.2
Combined	74.5 ± 5.4	74.7 ± 6.2	75.7 ± 6.0	75.7 ± 6.9	74.8 ± 4.9	76.0 ± 6.4	73.7 ± 6.7	74.6 ± 6.8
Lean mass (kg)								
PRE	39.0 ± 3.8	41.7 ± 4.5	n/a	42.1 ± 4.9	n/a	42.0 ± 4.6	39.2 ± 4.4	42.5 ± 4.8
PERI	41.7 ± 0.41	40.4 ± 4.6	n/a	40.4 ± 4.8	n/a	39.9 ± 4.3	41.0 ± 3.1	40.6 ± 5.0
POST	40.3 ± 3.1	39.7 ± 4.3	n/a	40.3 ± 4.4	n/a	40.4 ± 4.4	40.4 ± 3.6	40.7 ± 4.7
Combined	40.0 ± 3.4	40.8 ± 4.4	n/a	41.1 ± 4.6	n/a	41.1 ± 4.4	40.0 ± 3.7	41.5 ± 4.6[a]
Body fat (%)								
PRE	36.6 ± 5.5	31.4 ± 6.9	n/a	31.0 ± 7.2	n/a	31.1 ± 7.7	35.5 ± 5.8	30.6 ± 7.4
PERI	36.4 ± 0.8	36.4 ± 7.4	n/a	35.9 ± 7.8	n/a	36.3 ± 7.0	35.7 ± 3.1	37.0 ± 7.7
POST	37.2 ± 4.8	36.5 ± 9.5	n/a	35.6 ± 9.0	n/a	35.2 ± 9.5	35.3 ± 4.9	35.3 ± 9.5
Combined	36.8 ± 4.5	34.1 ± 8.2	n/a	33.5 ± 8.0	n/a	33.5 ± 8.3	35.5 ± 4.8	33.4 ± 8.4
Cross-sectional plane muscle thickness (mm)								
Medial deltoid (mm)								
PRE	23.7 ± 2.5	23.4 ± 2.5	22.1 ± 2.5	22.9 ± 3.9	22.7 ± 3.8	23.5 ± 5.3	22.1 ± 3.5	23.3 ± 3.0
PERI	22.0 ± 3.3	21.5 ± 3.4	21.4 ± 5.2	21.7 ± 2.9	20.4 ± 2.9	23.3 ± 3.3	22.0 ± 4.4	24.6 ± 2.7
POST	21.9 ± 2.9	22.2 ± 4.1	22.3 ± 3.0	21.8 ± 2.7	22.2 ± 3.4	23.2 ± 3.9	21.2 ± 3.2	21.6 ± 3.4
Combined	22.5 ± 2.9	22.6 ± 3.4	22.0 ± 3.4	22.2 ± 3.3	21.9 ± 3.4	23.4 ± 4.4	21.7 ± 3.5	22.9 ± 3.3
Rectus femoris (mm)								
PRE	18.7 ± 3.0	19.9 ± 2.8	18.3 ± 2.6	19.7 ± 2.9	19.3 ± 2.9	20.8 ± 3.6	18.0 ± 3.4	20.6 ± 4.1
PERI	18.2 ± 4.0	19.7 ± 3.3	18.5 ± 3.3	19.8 ± 3.2	19.8 ± 3.6	21.1 ± 2.3	20.3 ± 3.5	20.9 ± 2.8
POST	15.7 ± 2.1	17.3 ± 3.4	16.6 ± 1.5	18.6 ± 3.8	17.2 ± 2.3	18.7 ± 3.9	16.2 ± 2.1	18.5 ± 3.6
Combined	17.2 ± 3.1	18.8 ± 3.3	17.6 ± 2.4	19.3 ± 3.3	18.5 ± 3.0	20 ± 3.6	17.7 ± 3.3	19.9 ± 3.8
Vastus intermedius (mm)								
PRE	16.3 ± 4.4	14.5 ± 3.2	15 ± 2.9	15.3 ± 2.8	16.5 ± 3.3	15.5 ± 3.0	15.5 ± 3.4	15.7 ± 3.5
PERI	13.7 ± 5.4	14.9 ± 2.9	14.7 ± 3.2	19.2 ± 5.2	12.8 ± 5.3	16.9 ± 3.8	16 ± 5.3	16.8 ± 4.3
POST	13.8 ± 4.2	13.8 ± 3.6	13.3 ± 3.2	14.6 ± 4.0	12.9 ± 3.1	14.7 ± 4.1	13 ± 3.6	15.4 ± 4.2
Combined	14.6 ± 4.5	14.3 ± 3.3	14.2 ± 3.1	15.8 ± 4.1[a]	14 ± 4.0	15.5 ± 3.6	14.6 ± 4.1	15.8 ± 3.9[a]
Longitudinal plane muscle thickness (mm)								
Medial deltoid (mm)								
PRE	24.4 ± 1.4	24.5 ± 2.6	23.5 ± 1.8	24.6 ± 4.6	24.4 ± 2.6	25.3 ± 5.0	22.4 ± 3.1	24.2 ± 3.2
PERI	25.0 ± 2.6	23.6 ± 3.6	23.5 ± 6.2	22.4 ± 2.3	22.0 ± 4.1	24.3 ± 3.0	23.5 ± 5.5	25.0 ± 3.1
POST	23.3 ± 3.7	24.0 ± 4.4	22.7 ± 3.6	23.2 ± 2.7	23.1 ± 4.1	24.8 ± 4.2	22.1 ± 3.4	23.0 ± 3.5
Combined	24.1 ± 2.8	24.1 ± 3.5	23.2 ± 3.8	23.6 ± 3.6	23.3 ± 3.6	24.9 ± 4.3	22.5 ± 3.8	23.9 ± 3.3
Rectus femoris (mm)								
PRE	18.2 ± 2.7	19.4 ± 3.0	17.7 ± 2.3	19.3 ± 3.3	18.7 ± 2.7	19.7 ± 3.6	17.5 ± 3.5	19.9 ± 3.4
PERI	18.5 ± 4.0	19.5 ± 2.8	18.2 ± 3.4	19.6 ± 4.1	18.1 ± 2.9	19.5 ± 3.2	18.1 ± 4.1	20.1 ± 2.8
POST	14.5 ± 2.3	16.8 ± 3.1	16.0 ± 1.8	17.9 ± 3.9	16.5 ± 2.4	17.7 ± 3.7	15.2 ± 2.7	17.7 ± 3.0
Combined	16.7 ± 3.4	18.5 ± 3.2	17.1 ± 2.5	18.8 ± 3.7	17.6 ± 2.7	18.9 ± 3.6	16.7 ± 3.4	19.1 ± 3.3
Vastus intermedius (mm)								
PRE	15.1 ± 4.2	14.0 ± 3.1	14.1 ± 2	14.2 ± 3	15.3 ± 2.3	14.7 ± 3.2	14.9 ± 3.4	14.7 ± 3.2
PERI	13.4 ± 5.3	14.8 ± 3.2	14.6 ± 3.1	15.4 ± 3.7	13.3 ± 5.1	15.6 ± 3.1	15.0 ± 6.1	15.5 ± 3.5
POST	12.2 ± 3	13.5 ± 3.6	12.4 ± 2.7	13.8 ± 3.6	12.1 ± 3.2	13.7 ± 3.6	12.3 ± 3.1	14.2 ± 4.0
Combined	13.4 ± 4.1	14 ± 3.3	13.5 ± 2.7	14.3 ± 3.3	13.4 ± 3.7	14.5 ± 3.3	13.8 ± 4.1	14.7 ± 3.5
Cross-sectional plane subcutaneous fat thickness								
Medial deltoid (mm)								
PRE	6.9 ± 1.4	7.7 ± 2.3	7.6 ± 2.1	7.2 ± 2	7.2 ± 1.9	7.4 ± 2	7 ± 2	7.1 ± 2.1
PERI	7.8 ± 2.5	7.4 ± 2.4	7.1 ± 2.1	7.3 ± 2.4	7 ± 1.7	7.5 ± 3	6.4 ± 1.3	7.3 ± 2.4
POST	6.6 ± 2.2	7.3 ± 2.4	7 ± 2.5	7.2 ± 2.2	6.9 ± 2.7	7.1 ± 2.2	6.5 ± 2.2	6.3 ± 1.7
Combined	7 ± 2.1	7.5 ± 2.3	7.2 ± 2.2	7.2 ± 2.1	7 ± 2.1	7.3 ± 2.3	6.6 ± 1.9	6.8 ± 2
Rectus femoris (mm)								
PRE	13.6 ± 3.8	14 ± 5.4	13.8 ± 4.3	14.2 ± 5.5	13.5 ± 4.1	14 ± 4.8	13.5 ± 4.3	14.1 ± 4.8
PERI	16 ± 4.7	13.5 ± 4.4	15 ± 4.6	13.4 ± 3.9	15.3 ± 4.4	13.8 ± 4.3	14.9 ± 4.8	13.7 ± 4.3
POST	13.4 ± 2.5	13.4 ± 4.3	14.1 ± 3.7	13.9 ± 4.8	13.9 ± 4.5	13.1 ± 4.5	12.8 ± 3.1	13 ± 3.6
Combined	14.1 ± 3.5	13.7 ± 4.7	14.2 ± 4	13.9 ± 4.9	14.1 ± 4.2	13.6 ± 4.5	13.5 ± 3.9	13.6 ± 4.2
Longitudinal plane subcutaneous fat thickness								
Medial deltoid (mm)								
PRE	7.5 ± 1.7	8.2 ± 2.7	8 ± 2.2	8 ± 2.5	7.8 ± 2.1	7.8 ± 2.4	7.2 ± 1.8	7.9 ± 2.3
PERI	8.9 ± 2.9	8 ± 2.4	8.2 ± 1.3	7.8 ± 2.3	8.2 ± 1.6	7.9 ± 3	7.9 ± 2.5	8 ± 2.3
POST	7.4 ± 2.4	7.9 ± 2.4	7.7 ± 2.5	7.8 ± 2.4	7.6 ± 2.3	7.6 ± 2.4	7.1 ± 2	7.5 ± 2.2
Rectus femoris (mm)								
PRE	14.6 ± 4.3	15.4 ± 5	16.1 ± 5.6	15 ± 5.1	16 ± 4.6	15.1 ± 4.7	15.5 ± 4.7	15.3 ± 5
PERI	17.7 ± 5	15.4 ± 5.2	16.8 ± 3.5	14.3 ± 4.8	15.9 ± 3.2	14.9 ± 5.2	16.6 ± 4.8	14.9 ± 5.3
POST	15.6 ± 3.8	15.3 ± 4.9	15.9 ± 4.2	15.2 ± 4.9	15.5 ± 4.1	14.6 ± 4.6	15.8 ± 4.2	14.5 ± 4.6
Combined	15.8 ± 4.3	15.4 ± 4.9	16.2 ± 4.4	14.9 ± 4.9	15.7 ± 3.9	14.8 ± 4.7	15.9 ± 4.3	14.9 ± 4.8

Lean mass and percentage body fat reported in a subset of CON (n = 18) and EXC (n = 24).
Values represent mean ± SD; significance set at $P < 0.05$.
[a] Significant difference from week 0.

conditions and menopause groups (Supplemental Table 3, Supplemental Digital Content; all $P > 0.05$, http://links.lww.com/MSS/D118).

Questionnaires. QoL displayed an overall improvement in EXC (Supplemental Table 4, Supplemental Digital Content, http://links.lww.com/MSS/D118) and enjoyment of exercise (GEQ). Specifically, total scores increased over the intervention period in EXC (2918 ± 311 to 3120 ± 296 AU, $P = 0.008$), while remaining unchanged in CON (2883 ± 478 to 2842 ± 533 AU; $P > 0.05$). The increase in EXC was largely driven by the improvement in "Energy and Fatigue," with a 23% ± 40% increase from baseline (54 ± 15 to 65 ± 17 AU, $P = 0.002$), and "Social Functioning," which increased in EXC from 93 ± 11 to 96 ± 9 AU ($P = 0.043$). All other QoL domains did not change throughout the intervention. Sleep quality and sleep efficiency did not change over the intervention period between intervention conditions and menopause groups (Supplemental Table 4, Supplemental Digital Content, http://links.lww.com/MSS/D118). Enjoyment of exercise in the PRE and PERI menopause conditions did not change over 12 wk in CON (45.5 ± 5.2 to 45.3 ± 6.1 and 51.8 ± 6.0 to 50.5 ± 6.1 AU, respectively; $P > 0.05$), but there was a 6% ± 8% decrease in the POST menopause condition (52.5 ± 4.9 to 48.9 ± 5.2 AU, $P = 0.02$; Supplemental Table 4, Supplemental Digital Content, http://links.lww.com/MSS/D118). From a comparable baseline in the EXC condition, GEQ score increased by 8% ± 14% in PRE (46.8 ± 6.8 to 50.1 ± 5.4 AU, $P = 0.004$) and 13% ± 12% in POST (48.1 ± 6.6 to 53.7 ± 5.8 AU, $P < 0.001$) menopause conditions, respectively, with no change in EXC PERI observed.

DISCUSSION

The aim of the present study was to investigate the effect of a novel 12-wk dynamic low-impact body weight and resistance band exercise training program on muscle mass, strength, balance, and flexibility, with a focus on the lower limbs and hips, in healthy females aged 40 to 60 yr stratified into premenopausal, perimenopausal, and postmenopausal groups. The major findings of the present study were that hip strength, dynamic balance, flexibility, and lean body mass increased following the training program, with some measures of hip strength and balance increasing after just 4 wk. In contrast to our hypothesis, these increases were mainly comparable in premenopausal, perimenopausal, and postmenopausal groups, with some measures of balance actually appearing to increase to a greater degree in postmenopausal females. Taken together, this would suggest that the menopause transition and associated decline in sex hormone production may not affect the ability to adapt to a resistance exercise training program.

Given that greater hip strength is associated with increased femoral neck bone mineral density and reduced incidence of falls (11,12), maintaining skeletal muscle strength in females is vitally important. To our knowledge, this is the first study to determine how the menopause transition affects the ability of hip strength per se to adapt to resistance exercise training, in large part due to including perimenopausal females. Previous studies in females of 40–60 yr old have focused on postmenopausal females (17,37), included participants prescribed HRT (18,37), or not reported results based on menopause status (18,38,39). Thus, we report for the first time that hip abduction and flexion strength can be increased by 19% and 20%, respectively, with 12 wk of low-impact resistance exercise training and, importantly, that the magnitude and time-course of increase was comparable across premenopausal, perimenopausal, and postmenopausal females. The increase in hip flexion strength observed in our study is similar to that seen in other traditional progressive "resistance machine" training programs of other muscles of the lower limbs (17,18,37–40), but not as great as seen in "free weight" resistance exercise training programs (14,41), where 30% to 50% increases in squat strength have been observed after similar training durations in 40- to 60-yr-old females. However, it is important to note that strength of the hip flexors and abductors, which cannot generate as much force as other typical lower limb muscle movements, was not measured in any of these studies, making direct comparisons difficult. Interestingly, there was no effect of our training program on shoulder strength, as it increased by around 10% in both exercise and control groups. Although this finding is in line with a previous resistance band exercise training study in postmenopausal females that found increases in lower limb and trunk, but not upper limb, muscle strength (42), we propose that the increases in shoulder strength in both groups are likely a training effect of the four-weekly isometric dynamometer measurement protocol, of which the movement pattern, contractile speed, and loading modality are likely not experienced in everyday life (43). Nevertheless, the increases in shoulder strength were comparable in premenopausal, perimenopausal, and postmenopausal females.

The decline in strength in females between the ages of 40 and 60 yr is also associated with reduced balance, particularly in the lower limb hip flexor and abductor muscles (7,8). Given that maintaining balance and flexibility of the lower limbs are also important in reducing risk of falls later in life (12), we focused our training program on improving balance and flexibility of the lower limbs and hips in particular. We found greater than 10% improvements in lower body dynamic balance in the posterolateral and posteromedial directions after the resistance exercise program, both of which are focused on hip stability, but not the anterior direction, which has an ankle flexibility component to the movement. These data are comparable to, if not better, than a previous study investigating traditional "machine-based" lower limb resistance exercise in older postmenopausal females, which showed a ~7% increase in dynamic balance of the lower limbs using the Y-balance test (44), and in line with meta-analyses demonstrating a positive impact of resistance exercise on balance in older adults (45). We also found an improvement in lower body flexibility of 21% after 12 wk of training, which is comparable to increases seen with more traditional resistance exercise in older females (16,46,47). Of interest was that balance and flexibility improved to a comparable degree in premenopausal, perimenopausal, and postmenopausal females, with anterior balance only improving in postmenopausal females, again suggesting that there does not appear to be a decline in the ability of postmenopausal females to adapt to low-impact resistance exercise.

The present study demonstrated an increase of around 2% in lean body mass across all menopause groups. However, it is difficult to determine where this increase resided as, although there was a 12% increase in vastus intermedius muscle thickness, with no difference between menopause groups, this was only observed in the cross-sectional plane. Also, a statistical increase in thickness of the rectus femoris, which is responsible for hip flexion, was not observed with training. Previous studies have also reported around a 2% increase in lean body mass in perimenopausal and postmenopausal females under the age of 60 yr, but with no statistically significant change in computed tomography (CT)–measured quadriceps muscle cross-sectional area, following 1 yr of twice-weekly (48) or 12 wk of thrice-weekly (49) high-impact lower limb resistance exercise training. In contrast, the study of Isenmann et al. (14), which demonstrated that twice-weekly, moderate-, but not low-, intensity "free weight" resistance exercise training for 10 wk increased ultrasound-measured quadriceps muscle thickness by around 5% in both premenopausal and postmenopausal females. The discrepancies in the change in muscle cross-sectional area between these studies are difficult to reconcile but may be related to changes in muscle quality, as Taaffe et al. (48) also observed improvements in CT attenuation with exercise training.

From a mechanistic point of view, the reduction in skeletal muscle strength, balance, and mass in females during and after menopause is often attributed to a dramatic decline in production of sex hormones. Indeed, a dramatic decline in specific muscle force of the adductor pollicis muscle of the hand observed in perimenopausal females has been demonstrated to be prevented with HRT (50). Moreover, several studies have demonstrated that HRT (estrogen alone or in combination with testosterone and/or progesterone), with or without resistance exercise training, can increase muscle strength and hypertrophy (51,52), particularly in the early postmenopausal period (53). Indeed, estrogen replacement can increase skeletal muscle protein and collagen synthesis in response to exercise (54), and appears to reduce markers of protein breakdown in early, but not late, postmenopausal females (55). In contrast, testosterone and progesterone, but not estrogen, appear to increase muscle protein synthesis in older postmenopausal females (56). Interestingly, however, we did not observe any baseline differences in the present study between menopause groups in muscle mass, specific strength, balance, or flexibility, despite a clear decline in serum 17β-estradiol and progesterone, and increase in age, across premenopause to postmenopause. The lack of effect is perhaps due to the comparable habitual physical activity levels and body composition between the groups, particularly given that detailed cross-sectional studies of premenopausal, perimenopausal, and postmenopausal females between 40 and 60 yr old suggest that the decline in lower (but not upper) limb strength and flexibility across the menopause transition may be prevented with increased physical activity (13). Given that measures of habitual physical activity are generally reliant on lower, not upper, limb movement (e.g., step count), this may suggest that declines in physical activity across the menopause transition play a permissive role in the effect of reduced circulating sex hormones on muscle strength. Whether this effect persists past 60 yr of age is not known and requires further investigation, particularly as older postmenopausal females have perturbed muscle protein turnover that appears insensitive to estrogen (57), and do not always improve lower body muscle strength and function with HRT (48,58), perhaps due to specificity of estrogen to muscle fiber type (51), the composition of which is known to change with advancing age.

To conclude, this is the first study to demonstrate that the menopause transition, associated decline in sex hormones and increase in age, does not appear to affect the ability of lower limb (hip) strength and balance to adapt to increased physical activity and exercise training in females not taking HRT. Limitations of the present study include reduced power, in part due to 2:1 recruitment to the exercise group, which may have limited ability to detect differences between menopause groups. However, when we perform individual two-way ANOVAs within each menopause status group (time–intervention for EXC vs CON), we are able to detect increases strength, balance, and flexibility with EXC, which would indicate that the benefits of the program are achievable within each group and can be detected in relatively low numbers of participants. Moreover, when we increase statistical power by performing a two-way ANOVA in just the EXC group (i.e., without CON), we still do not see any differences between menopause groups in the improvement in strength, balance, and flexibility. Thus, a longer intervention period may be required to detect any differences between the menopause groups due to the low-impact nature of the exercise program, and despite following an online home-based program, performing exercise under supervised conditions in a group scenario may limit applicability to an individual performing exercise at home alone. From a more holistic health point of view, we did not see any adverse effects of the program, and we found that our exercise training program improved quality of life and enjoyment of exercise, which may be particularly important across the perimenopausal period where energy expenditure is thought to decline. The improved blood lipid profile, with no change in total body or fat mass, also warrants further investigation given that cardiovascular health worsens in and after the menopause such that older females are affected to a greater degree than males.

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Data Availability: Data described in the manuscript may be made available upon request, pending application.

BASIC SCIENCES

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