Title: A blended gym- and home-based resistance training does not compromise gains in muscle mass and function in untrained, pre-menopausal females

Authors: Sarah E. Alexander[1*], Olivia E. Knowles[1], Briana Gatto[1], Paul Jansons[2], Brad Aisbett[2], Glenn D. Wadley[2], Danielle Hiam[2] and Séverine Lamon[2]

[1] School of Exercise and Nutrition Sciences, Deakin University, Geelong

[2] Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Deakin University, Geelong

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*Corresponding Author:

Sarah Alexander; School of Exercise and Nutrition Sciences, Deakin University, 221 Burwood Hwy, Burwood 3125, Australia.

ph (+61 3) 9244 5571

Email: sealexa@deakin.edu.au

ABSTRACT

Objectives: Resistance training increases muscle mass and strength in males and females. Resistance training programs targeting muscle hypertrophy and strength are usually based on heavy weights and a low number of repetitions. The SARS-CoV-2 pandemic has limited the opportunity to deliver resistance training programs that require on-site access, which has often led to the prescription of alternative, home-based resistance training programs using considerably lighter weights.

Design and Methods: In this study, 20 untrained, pre-menopausal females underwent a 12-week resistance training program. A sub-cohort of participants (n=9) performed a period of home-based training with a modified program, while the remaining cohort (n=11) performed 100% of their training sessions in a gym-based environment.

Results: There were no significant differences in muscle strength, mass or power gains, the progression trajectory between participants who completed a blended or gym-based program. Total and free testosterone concentrations did not change with training or differ between groups.

Conclusions: A home-based training program may therefore provide a reliable, short-term solution to disruptions to resistance training research and conditioning practice.

Key words: strength, hypertrophy, female, resistance training, androgens

INTRODUCTION

Resistance exercise is structured physical exercise involving muscle contraction against an external load[1]. Chronic resistance training increases muscle mass and strength in males and females across the lifespan. In pre-menopausal, untrained females (*n*=19), eight weeks of structured resistance training significantly improves upper and lower body strength by 15% and 12%, respectively, and increases whole body lean mass by 4%[2]. To optimise increases in muscle strength and hypertrophy, resistance training programs traditionally prescribe heavy loads above 60% of an individual's repetition maximum (RM) and a relatively low number (6-12) of repetitions[3].

Resistance exercises commonly rely on access to exercise equipment to perform multi-joint exercises using heavy barbells (e.g., squat rack) or to target specific muscle groups or joint actions (e.g., leg extension machine). During the SARS-CoV-2 pandemic, geographical movement restrictions and physical distancing measures limited access to gyms or research facilities with such weights and machines. Home-based resistance training programs may however provide a viable alternative for practitioners and researchers to continue training their clients or participants during lockdowns and prevent significant setbacks in health, performance and research outcomes. Home-based workouts typically use lower weights and do not rely on machine-based equipment and heavy weighted barbells and dumbbells. While traditional resistance training guidelines recommend using heavy weights, loads below 60% of an individual's 1RM can induce similar levels of skeletal muscle hypertrophy[4] and strength[5], provided the individual performs the exercise to failure. This suggests that appropriately prescribed home-based resistance training programs that utilise lower weights and higher repetitions may be effective at increasing muscle mass and function.

The current project investigated the effects of a 12-week resistance training intervention aimed at maximizing strength and hypertrophy gains in 20 untrained, premenopausal females. Here, we report a comparison of the efficacy of a period of blended home- and gym-based resistance training to substitute a gym-based training program due to SARS-CoV-2 restrictions in two sub-cohorts of participants (blended, *n*=9, gym-based, *n*=11).

METHODS

This research was granted ethical approval by the Deakin University Human Research Ethics Committee (DUHREC 2018-388). All participants provided written, informed consent before taking part in the study, which was conducted in accordance with the *Declaration of Helsinki*[6].

Twenty healthy females aged 18-40 years were recruited from the general population. Participants were not resistance trained (defined as having performed structured resistance training at least twice per week for the last six months), pregnant or breastfeeding, did not smoke and displayed no contraindications to exercise according to the Exercise and Sports Science Australia adult pre-exercise screening system[7]. Participants were excluded if they had a history of anabolic hormone use, used medications or supplements that could affect the anabolic response to training, or if their daily protein intake was outside the Australian dietary guidelines of 15-25% total macronutrient intake, measured through a mobile phone application for four days including one weekend day (*Easy Diet Diary*[8]). The health, fitness and anabolic status of young, healthy females are not expected to change over a 12-week period as a passage of time; therefore, each participant acted as her own control in a pre-post study design. The ovulatory phase of the menstrual cycle was avoided for pre- and post-training testing. The data collection period lasted 12 weeks, three full cycles of a typical menstrual cycle lasting 28 days, allowing each participant to undergo pre- and post-testing during the same phase of their cycle. Menstrual phases were verified through menstrual diaries and hormonal analysis, in line with published guidelines for the inclusion of females in exercise physiology cohorts[9, 10]. As each participant acted as her own control, we did not exclude participants based on hormonal contraceptive (HC) use but accounted for HC use in statistical models.

Prior to beginning the training program, all participants attended three gym-based familiarisation sessions to ensure participants learnt any unfamiliar movements and reduce any learning effect[11]. An exercise scientist coached the participants through all the testing and training exercises with little-to-no weight[12].

Participants' RM was assessed for leg press, squat, leg extension, hamstring curl, seated row, dumbbell shoulder press and biceps curl. Leg press was included in the strength testing but not in the training program and was considered the primary outcome measure for muscle strength, as it was deemed the most accurate measure of muscle strength without the confounding effects of learning.

Lower body 1RM was calculated from 5-RM tests using the following equation: $estimated\ 1RM = 4.67 + (1.14 \times weight\ lifted)$[13]. Upper body 1RM was calculated from 10RM tests to avoid untrained participants lifting heavy free-weights above their heads using the following equation: $estimated\ 1RM = 1.43 + (1.20 \times weight\ lifted)$[13].

Peak muscle power output was assessed using a portable force plate *(AMTI, Watertown, MA).* Participants performed a countermovement jump (CMJ) by putting their hands on their hips and jumping as high as possible after a squatting movement, without the use of an arm swing. Participants had four attempts at the jump and the best attempt was recorded.

Blood samples were collected in the fasted state before and after the training program, as well as every two weeks throughout the training program.

Medical images of the thigh in the dominant leg (50% femur length) were taken using XCT 3000 peripheral quantitative computed tomography (pQCT) *(Stratec Medizintechnik GmBH, Pforzheim, Germany)* to assess the cross-sectional area (CSA) of the thigh muscle groups (quadriceps and hamstrings). In our laboratory, pQCT shows excellent test-retest reliability (intraclass correlation coefficient; $ICC_{2,1}$ 1.00) for the measurement of muscle area in males and females aged 18-50 years[14].

Every Monday, Wednesday and Friday morning, participants arrived at the training facility after an overnight fast. The training parameters were chosen according to the current American College of Sports Medicine (ACSM) guidelines for increasing muscle hypertrophy and strength[3] and are detailed in Table 1. Squat, leg extension, hamstring curl and seated row were performed on Keiser pneumatic weight machines *(Keiser, Fresno, CA)*, which have excellent test-retest reliability for leg press 1RM (intraclass correlation coefficient = 0.972, $p < 0.001$) and low coefficients of variation (leg press 1RM = 6.3%)[15]. Shoulder press and biceps curls were performed with free-weights. Volume load was calculated as the number of repetitions performed × number of sets × the relative intensity of the exercise (fraction of 1RM)[16].

Table 1. Resistance training programs prescribed to participants (n=20). The gym-based program was followed by all participants when access to the gym was possible. The home-based program was prescribed to a sub-cohort of participants (n=9) when access to gyms was not possible. AMRAP = as many repetitions as possible.

Gym-based training program							
Exercise	Sets	Reps	Intensity (%RM)	Rest between sets (s)	Tempo (s)	Volume load (reps × sets × intensity)	Targeted muscle group
Squat	3	8	80	90	2,0,2,0	19.2	Quadriceps Gluteals
Leg extension	3	8	80	90	2,0,2,0	19.2	Quadriceps
Hamstring curl	3	8	80	90	2,0,2,0	19.2	Hamstrings
Seated shoulder press	3	9	70	90	2,0,2,0	18.9	Deltoids Biceps Trapezius
Seated row	3	10	60	90	2,0,2,0	18.0	Trapezius latissimus dorsi triceps
Home-based training program							
Squats	3	15 (last set AMRAP)	Approximately 45% RM	90	2,0,2,0	20.25	Quadriceps gluteals
Forward lunges	3	$15 \cdot leg^{-1}$ (last set AMRAP)	Approximately 45% RM	90	2,0,2,0	20.25	Quadriceps gluteals hamstrings
Hamstring sliders	3	10 (last set AMRAP)	Body weight	90	2,0,2,0	N/A	Hamstrings

Seated Shoulder press	3	9 (last set AMRAP)	70% RM	90	2,0,2,0	18.9	Trapezius latissimus dorsi triceps
Bent over row	3	9 (last set AMRAP)	70% RM	90	2,0,2,0	18.9	Deltoids Biceps Trapezius
Seated biceps curl	3	9 (last set AMRAP)	70% RM	90	2,0,2,0	18.9	Biceps Brachii

Upper body exercises were performed at 70% RM to increase the safety of untrained participants. To maintain a similar overall volume load (repetitions × sets × intensity), the repetitions for upper body exercises increased from eight to nine[3]. All exercises were performed at a 2-0-2-0 tempo, whereby the concentric and eccentric phases of each lift lasted two seconds each, with no pause at either the top or bottom of the exercise. The tempo was set at 60 beats$\cdot$min^{-1}. Progressive overload (increase weight lifted by 5%) occurred when participants were able to complete two additional repetitions in the last set of each exercise in two consecutive training sessions[17].

Participants arrived fasted to each training session but consumed a 25-g standardised protein supplement (*Ascent Protein, Denver, CO)* that had earned Informed Choice approval to standardize macronutrient consumption and optimise the effect of the exercise stimulus[18].

Due to the SARS-CoV-2-related lockdowns experienced throughout Victoria, Australia in 2020 and 2021[19], a sub-cohort of participants (n=9) undertook a portion of their training sessions at home delivered via Zoom, at 7:30AM on Mondays, Wednesdays, and Fridays, replicating the time and days of the gym-based training sessions. Table 1 outlines the program prescribed for these sessions.

Due to the unavailability of heavy barbells, the prescribed weight for lower body exercises could not be maintained at 80% of the participants' 1RM. Instead, they were given a weight that allowed them to complete 15 repetitions of a given exercise (approximately 45% of their 1RM). Given the lower loads performed at home and the untrained status of participants, prescribing "as many repetitions as possible" (AMRAP) in the final set increased the likelihood that high threshold motor units were recruited, so to stimulate increases in muscle strength to a similar magnitude as the high load gym-based program[5].

Similarly, exercises that replicate similar movements as leg extension and hamstring curls (forward lunges and hamstring sliders) and target the same muscle groups were prescribed to mimic the gym-based program as closely as possible (Table 1). Overall volume load was maintained between the gym-based and at-home training interventions. Participants were given the same standardised protein supplement to consume at home. Participants spent between 2 and 6 sessions home-based at various stages of the twelve-week program before returning to the regular gym-based sessions. The average number of sessions undertaken at home was four sessions out of a possible 36 (11%).

Forty-eight hours after the final session, all baseline measures were repeated as described above for all participants, including strength testing, where participants were blinded to the load displayed on the Keiser equipment.

Testosterone (sensitivity 0.18 $ng \cdot mL^{-1}$, intra-assay coefficient of variation (CV) 3.1-5.4%, inter-assay CV 4.2-7.4%) and sex hormone binding globulin (SHBG) (sensitivity 0.23 $nmol \cdot L^{-1}$, intra-assay CV 2.3-4.8%, inter-assay CV 5.2-6.3%) were measured via Enzyme-Linked Immunosorbant Assay *(IBL International, Hamburg, Germany)* according to manufacturer's instructions.

All data were analysed using R studio version 4.0.2. Unpaired t-tests were used to compare participants' characteristics between the gym-based participants and blended program participants. A linear mixed model was used to examine whether the outcome measures; muscle mass, strength or power were altered by the resistance program and to assess differences in outcome measures between participants who completed a blended or gym-based program (group). The model was of the form:

$$Outcome = Timepoint * Group + random\ intercept\ (ID)$$

Fixed effects were timepoint and group and the interaction between timepoint and group. The random intercept was participants unique ID that accounted for differences in the outcome measure at baseline and repeated measures.

Before fitting the linear mixed models, akaike information criterion tests were run and established that none of the models needed to be adjusted for hormonal contraceptive use. R packages *lme* [20], *lmerTest*[21], *tidyverse*[22] *MASS*[23] and *lmtest*[24] were used in our analyses.

RESULTS

There were no differences in age (mean ± SD, 25.3 ± 5.0 gym-based, 21.9 ± 3.9 blended, p = 0.12) or BMI (22.8 ± 3.3 gym-based, 24.5 ± 4.1 blended, p = 0.30) at baseline. There was no difference between groups for the calculated baseline 1RM for any exercise except leg extension, where the gym-based cohort displayed a higher 1RM compared to the blended program cohort (p=0.04). Six participants (55%) in the gym-based cohort and six participants (67%) in the blended cohort were currently using hormonal contraceptives (HC) (p=0.61). Participant characteristics and baseline 1RM are listed in Table 2. Supplementary Table 1 provides a break-down of the different types of OC used by the participants in each cohort.

*Table 2. Anthropometric and strength data for all participants. P-values are for pairwise comparisons to gym-based participants using unpaired t-tests. * indicates statistical significance (p<0.05).*

	Gym-based participants (*n*=11)	**Blended program participants (*n*=9)**
Age (years)	25.3 ± 5.0	21.9 ± 3.9 (*p* = 0.12)
Height (m)	1.7 ± 0.1	1.6 ± 0.1 (*p* = 0.30)
Weight (kg)	64.5 ± 9.6	66.3 ± 11.1 (*p* = 0.70)
BMI (kg·m^{-2})	22.8 ± 3.3	24.5 ± 4.1 (*p* = 0.30)
Hormonal contraceptive use	Users: 55% Non-users: 45%	Users: 67% Non-users: 33% (*p* = 0.61)
Calculated squat 1RM (AU)	92.9 ± 33.6	105.4 ± 24.3

		(p = 0.33)
Calculated leg press 1RM (AU)	163.6 ± 33.4	180.1 ± 27.5 (p = 0.22)
Calculated leg extension 1RM (AU)	56.8 ± 10.4	45.9 ± 13.0 (p = 0.04)*
Calculated hamstring curl 1RM (AU)	37.0 ± 6.7	36.9 ± 6.9 (p = 0.97)
Calculated seated row 1RM (kg)	40.7 ± 6.4	38.4 ± 7.3 (p = 0.45)
Calculated shoulder press 1RM (kg)	9.1 ± 2.4	8.7 ± 2.4 (p = 0.70)
Calculated biceps curl 1RM (kg)	8.3 ± 1.6	8.4 ± 1.4 (p = 0.67)

The trajectory of working weight increased in all resistance exercises regardless of the training program. Squat increased by 1.2 kg per session (β = 1.2 kg, SE = 0.14, $p < 0.001$), leg extension by 0.4 kg per session (β = 0.44 kg, SE = 0.10, $p < 0.001$), hamstring curl by 0.2 kg per session (β = 0.21 kg, SE = 0.03, $p < 0.001$), shoulder press by 0.1 kg per session (β = 0.13 kg, SE = 0.01, $p < 0.001$), seated row by 0.2 kg per session (β = 0.2 kg, SE = 0.10, $p = 0.04$) and biceps curl by 0.09 kg per session (β = 0.09 kg, SE = 0.01, $p < 0.001$). There was a significant interaction between the training group and the working weight trajectory in the squat exercise, with a greater progression in participants who completed the blended program compared to the gym-based program (β = -0.42 kg, SE = 0.19, $p = 0.04$), but no differences in the trajectory of working weight in any other exercise. This indicates that, for all exercises except the squat, participants improved at the same rate regardless of whether they completed the blended or gym-based programs (Figure 1).

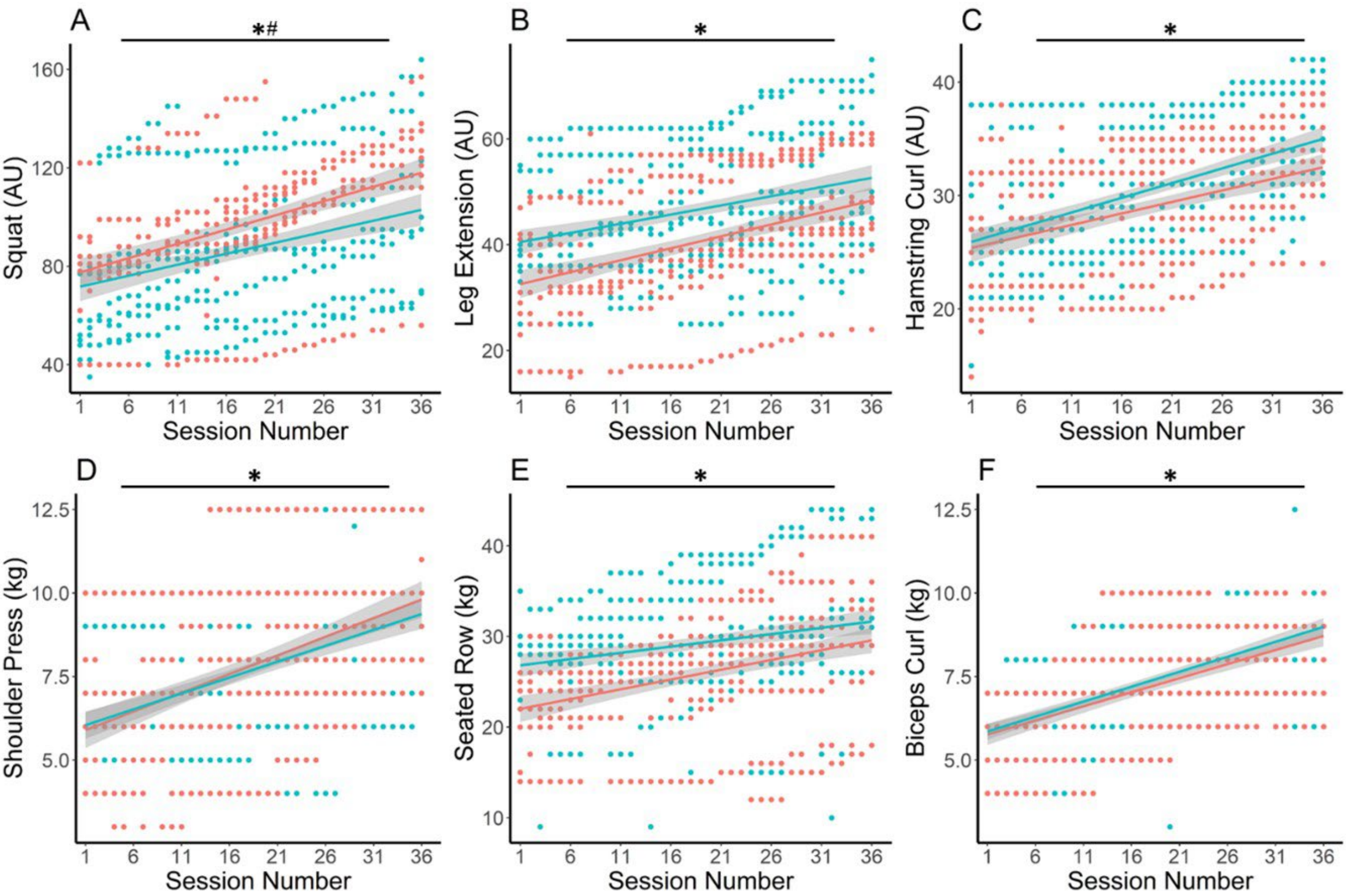

*Figure 1. The trajectory of working weight progression for a) squat, b) leg extension, c) hamstring curl, d) shoulder press, e) seated row and f) biceps curl. Participants undertaking a 12-week gym-based training program are denoted in blue (n=11), and participants undertaking the blended resistance training program are denoted in red (n=9). * indicates a significant difference from session 1 to 36. # indicates a significant interaction between group and time. p <0.05 was deemed significant.*

All participants improved their working weight for each exercise from baseline to post intervention, with no difference between groups (Figure 3). Squat weight improved by 38.8 kg (β = 38.83 kg , SE = 4.45, $p < 0.001$), leg extension by 14.2 kg (β = 14.21 kg, SE = 2.89, $p < 0.001$), hamstring curl by 10.4 kg (β = 10.37 kg, SE = 1.84, $p < 0.001$), shoulder press by 3.2 kg (β = 3.21 kg, SE = 0.42, $p < 0.001$), seated row by 7.8 kg (β = 7.77 kg, SE = 2.06, $p < 0.01$) and biceps curl by 2.9 kg (β = 2.86 kg, SE = 0.39, $p < 0.01$) (Figure 2).

After 12 weeks of the training program, leg press 1RM improved by 48.0 kg (β = 47.99 kg, SE = 8.81, $p < 0.001$) and thigh muscle CSA increased by 7.0 cm^2 (β = 6.99 cm^2, SE = 2.28, $p < 0.02$), with no significant difference in the response to training between groups (Figure 2). Power did not significantly increase with training (β = 210.14, SE = 164.26, p = 0.22) in either group (Figure 2).

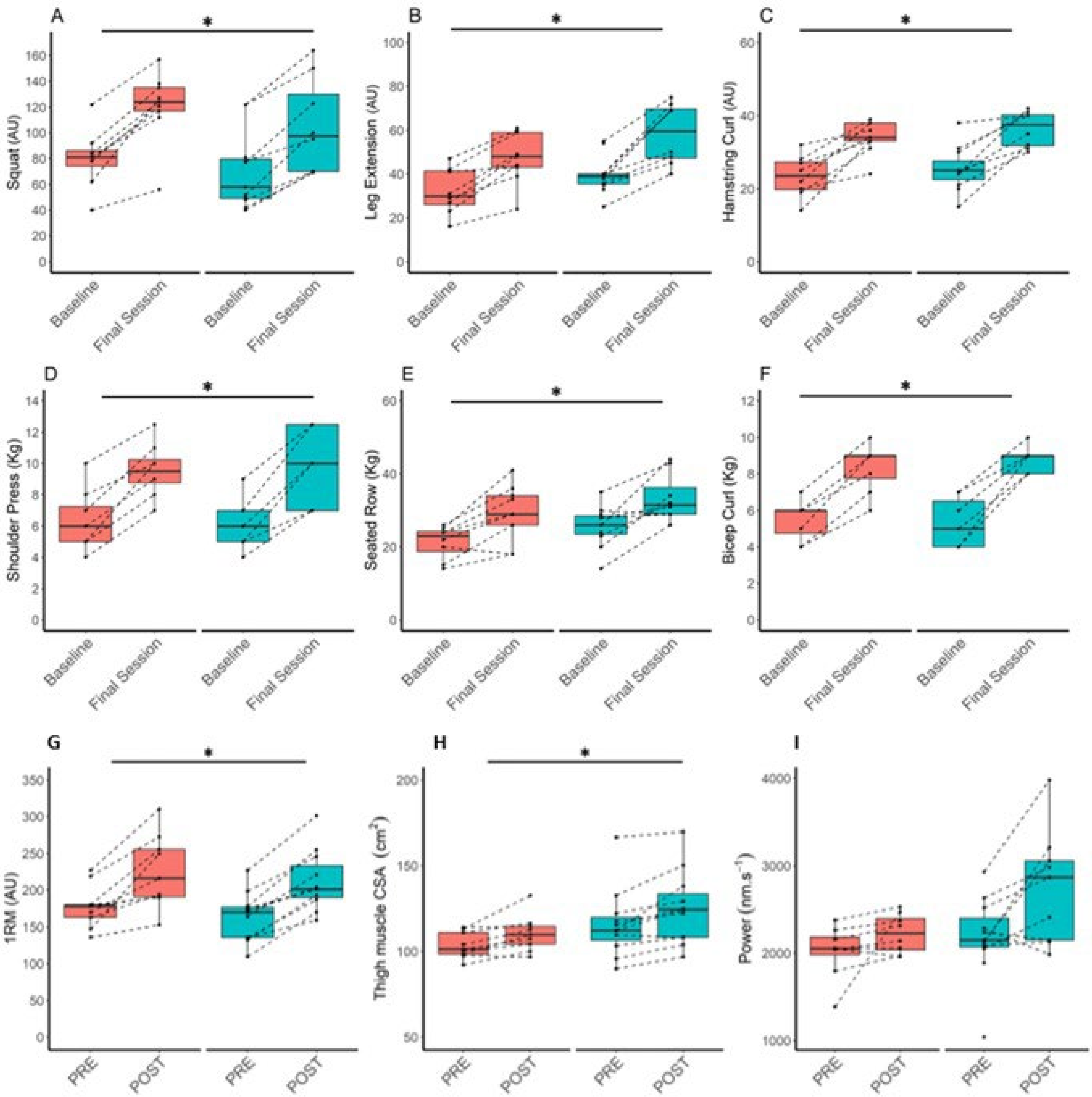

Figure 2. Working weight used in the first session (BASELINE) and final session. A) squat, B) leg extension, C) hamstring curl, D) shoulder press, E) seated row and F) biceps curl. Changes that occurred to G) muscle strength (leg press 1 RM), H) thigh muscle cross sectional area (CSA) and I) power at baseline (PRE) and in response to a 12-week resistance training program (POST).

*Participants undertaking a 12-week gym-based training program are denoted in blue (n=11), and participants undertaking the blended resistance training program are denoted in red (n=9). * indicates a significant difference from Baseline to Final Session. # indicates a significant interaction between group and time. p <0.05 was deemed significant.*

Testosterone, SHBG and free androgen index (FAI), which is calculated as $\frac{(total\ testosterone\ (nmol{\cdot}L{-}1)}{sex\ hormone\ binding\ globulin\ (nmol{\cdot}L{-}1)}$ x 100 and is indicative of the concentration of bioavailable testosterone, did not change with resistance training. These hormones did not display different responses after the blended or gym-based training program (Figure 3).

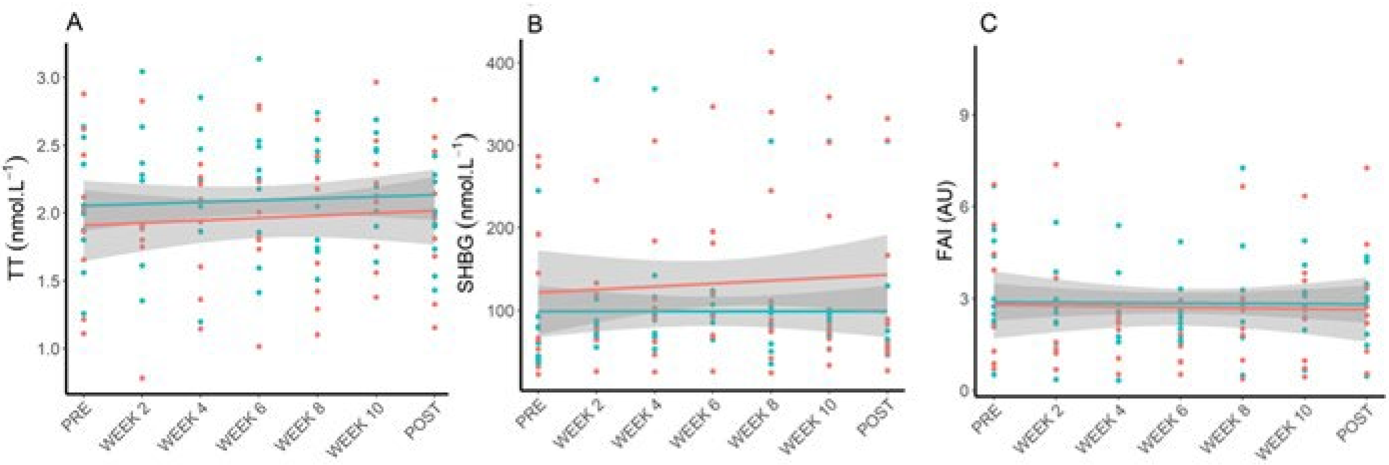

*Figure 3. Hormone levels across 12 weeks of resistance training. (a) Total testosterone (TT), (b) sex hormone binding globulin (SHBG) and (c) free androgen index (FAI). Participants undertaking a 12-week gym-based training program are denoted in blue (n=11), and participants undertaking the blended resistance training program are denoted in red (n=9). * indicates a significant difference across time, # indicates a significant interaction between group and time. p <0.05 was deemed significant.*

DISCUSSION

The SARS-CoV-2 pandemic resulted in wide-spread lockdowns and restricted access to fitness facilities in Victoria, Australia[19]. To circumvent this, we introduced a blended home- and gym-based substitute to a 12-week resistance training program. Our data suggest that this blended program was as effective at increasing muscle strength and size as a gym-based program in pre-menopausal females aged 18-40 and did not impair participant progression trajectory.

A blended program that includes up to two weeks of low-load, home-based resistance training may serve as an effective proxy for a 12-week, high-load gym-based program. While the trajectory of squat progression was different between groups by 0.4 kg per session, the overall effect of the training on muscle strength was not different. This is supported by our primary strength outcome measure, where leg press 1RM (which was not trained and therefore rules out a learning effect) was not different between the two cohorts post-training. The slight delayed increase in squat weight in the gym-based group indicates that a period of low-load, high-repetition training mid-way through a training program may allow for recovery after beginning a high-load training regime and enhance progression thereafter.

The design of the current study was borne out of necessity due to the snap-lockdowns that occurred in Victoria, Australia, in 2020 and 2021[19]. This involved a maximum of two weeks of home-based training before participants could return to the research facility, and the effect a period of home-based training lasting longer than two weeks would have on muscle strength and hypertrophy cannot be inferred from our data. However, previous literature from similar cohorts report that, in line with our results, there were no differences in muscle size or strength gains between low- or high-load resistance training in untrained females (*n*=13[25], *n*=11[26], *n*=23[27]) in gym-based programs lasting six to 12 weeks. Whether such findings can be repeated in a home-based setting provides an opportunity for future research.

Finally, anabolic hormone levels may influence muscular adaptations to resistance training[28, 29] by triggering signalling cascades that lead to key physiological adaptations, such as the activation of muscle protein synthesis. Hormone levels did not change with time or between training regimes, therefore indicating that, in future resistance training studies in untrained females, missed time points may be addressed through statistical methods such as data imputation.

Limitations

Due to the nature of this study, no *a priori* hypothesis was made and some limitations associated with our results should be addressed. The number of sessions undertaken at home was not consistent between all participants. Similarly, the home-based training took place at different stages of the 12-week program (weeks five and six on average). Adaptations to resistance training follow different time courses. In untrained individuals, neural adaptations occur within the first two to four weeks of a training program while the hypertrophic response is delayed and occurs after at least six weeks of training [30]. Because of this, participants undergoing the home-based training at different stages of the program may have experienced different training adaptations.

PRACTICAL IMPLICATIONS

- Substituting a gym-based resistance program with a blended home- and gym-based program increases muscle size, strength, and power to a similar extent as a solely gym-based program in untrained, pre-menopausal females. While two weeks of home-based training may not be enough of a perturbation in training to elicit different training adaptations, it may allow researchers to continue their training studies throughout future lockdowns or other restrictions and prevent a loss of participants and data and unnecessary participant burden.
- Low-load, high-repetition resistance training is effective at increasing muscle mass and function provided "AMRAP" is prescribed, or an element of fatigue is introduced to maintain the efficacy of a low-load resistance training program. This knowledge may also be applied when traditional high-load resistance training programs are not possible due to injury, inaccessibility to equipment or safety considerations.
- Both total and free testosterone are stable with resistance training in untrained, pre-menopausal females. This suggests that if collection time-points are missed, these data points may be addressed through statistical measures such as multiple imputation.

Authorship contributions: SA, SL, BA and GW contributed to the research concept and study design, SA and OK performed the literature review, SA, BG and PJ collected data, DH performed data and statistical analysis and interpretation, and all authors contributed to the writing and reviewing of the manuscript.

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FIGURE LEGENDS

*Figure 1. The trajectory of working weight progression for a) squat, b) leg extension, c) hamstring curl, d) shoulder press, e) seated row and f) biceps curl. Participants undertaking a 12-week gym-based training program are denoted in blue (n=11), and participants undertaking the blended resistance training program are denoted in red (n=9). * indicates a significant difference from session 1 to 36. # indicates a significant interaction between group and time. $p < 0.05$ was deemed significant.*

*Figure 2. Working weight used in the first session (BASELINE) and final session. A) squat, B) leg extension, C) hamstring curl, D) shoulder press, E) seated row and F) biceps curl. Changes that occurred to G) muscle strength (leg press 1 RM), H) thigh muscle cross sectional area (CSA) and I) power at baseline (PRE) and in response to a 12-week resistance training program (POST). Participants undertaking a 12-week gym-based training program are denoted in blue (n=11), and participants undertaking the blended resistance training program are denoted in red (n=9). * indicates*

a significant difference from Baseline to Final Session. # *indicates a significant interaction between group and time.* $p < 0.05$ *was deemed significant.*

Figure 3. Hormone levels across 12 weeks of resistance training. (a) Total testosterone (TT), (b) sex hormone binding globulin (SHBG) and (c) free androgen index (FAI). Participants undertaking a 12-week gym-based training program are denoted in blue (n=11), and participants undertaking the blended resistance training program are denoted in red (n=9). * *indicates a significant difference across time,* # *indicates a significant interaction between group and time.* $p < 0.05$ *was deemed significant.*