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Periodization Strategies in Older Adults: Impact on Physical Function & Health

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ABSTRACT

Purpose: This study compared the effect of periodized versus non-periodized (NP) resistance training (RT) on physical function and health outcomes in older adults. **Methods:** Forty-one apparently healthy untrained older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were recruited and randomly stratified to a NP, block periodized (BP), or daily undulating periodized (DUP) training group. Outcome measures were assessed at baseline and following a 22-week x 3 $d \cdot wk^{-1}$ RT intervention, including; anthropometrics, body composition, blood pressure and biomarkers, maximal strength, functional capacity, balance confidence and quality of life. **Results:** Thirty-three subjects satisfied all study requirements and were included in analyses (female=17, male=16; 71.3 ± 5.4 y; 166.3 ± 8.5 cm; 72.5 ± 13.7 kg). The main finding was that all three RT models produced significant improvements in several physical function and physiological health outcomes, including; systolic blood pressure, blood biomarkers, body composition, maximal strength, functional capacity and balance confidence, with no between-group differences. **Conclusion:** Periodized RT, specifically BP and DUP, and NP RT are equally effective for promoting significant improvements in physical function and health outcomes among apparently healthy untrained older adults. Therefore, periodization strategies do not appear to be necessary during the initial stages of RT in this population. Practitioners should work towards increasing RT participation in the aged via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings.

Key Words: Resistance training, program, model, sarcopenia

INTRODUCTION

Sarcopenia is one of the major physiological processes associated with aging, characterized by a progressive decline in skeletal muscle mass. It is estimated that total muscle mass is lost at a rate of 1-2% per year above the age of 50 years (1, 32). Consequently, aging has a significant impact on neuromuscular function via marked decreases in maximal strength, with strength losses of 2.5-5.0% per year previously reported (1, 12). This strength loss is considered to be the main contributing factor to the reduced functional capacity and an increased risk of falls and physical disability observed in older adults (39).

At present, no single pharmacological or behavioral intervention has been proven as successful as resistance training (RT) for slowing the progression of sarcopenia, primarily via inducing skeletal muscle hypertrophy and subsequent body composition improvements (8, 39). Ample evidence supports substantial strength gains in older adults across both genders following RT (8, 38). Furthermore, RT is considered the primary intervention for increasing and maintaining functional independence among older adults, with marked improvements in activities of daily living (ADL) performance observed following RT (14, 16). Therefore, RT drives adaptations that have a significant impact on the quality of life (QOL) of older humans and is important for reducing the economic burden on healthcare. However, recent cross-sectional data indicate that only 4.4% of US adults aged $\geq$ 65 years participate in muscle-strengthening activities (21).

The American College of Sports Medicine (ACSM) recommend the use of free-weight and machine, multiple- and single-joint exercises for one to three sets per exercise with 60-80% of 1RM for 8-12 repetitions with 1-3 min of rest in between sets for 2-3 d·wk^{-1} (30). Progressive overload and training variety is also advocated, yet no specific guidelines are provided. These recommendations alongside the significant body of research investigating

RT in older adults highlights a large variation in the type of RT employed. Therefore, it is vital to determine what organizational structure of program variables is most optimal for counteracting the negative effects of aging. The process of organizing a training program considering all of these factors may be referred to as *periodization*.

Although lacking a universally accepted formal definition, periodization is a planning process typically applied in sport performance, aiming to achieve peak physical performance at a pre-determined time point(s), e.g. major competition, while minimizing the risk of overtraining. Traditional or linear periodization, demonstrates a progressive reduction in training volume while increasing training “intensity” (synonymous with “load” in a weightlifting context (35)), between and within training cycles. The principles of traditional periodization are commonly implemented using 4 week training blocks (mesocycles), i.e. block periodization (BP), which include highly concentrated workloads targeting a minimal number of training outcomes (i.e. maximal strength, hypertrophy). Alternatively, undulating periodization is characterized by a much more frequent manipulation of volume and intensity, resulting in what has been termed daily undulating periodization (DUP) . Specifically, volume and intensity are manipulated on a daily basis, hence increasing training variation thought to improve physiological and performance adaptations.

Despite a limited body of evidence, studies have demonstrated statistically superior improvements in maximal strength (18, 23, 24, 26, 36) following periodized versus non-periodized (NP) RT in young adults. Moreover, a meta-analysis of periodized and NP strength and power orientated RT programs concluded that periodization was a more effective training strategy across both genders, all age groups and various training backgrounds (31). Yet, when controlling for other variables, only a small effect size (ES) (0.25) was evident for periodized RT. Finally, a recent systematic review (37) concluded that although it is premature to endorse periodized training as superior to a NP program, periodization is a feasible means of prescribing exercise for sedentary adults. The authors highlighted the potential of periodization as significant due to the importance of establishing effective and sustainable training interventions for reducing disease burden and improving QOL.

Investigation into the application of periodization strategies specifically among older adults is lacking, with few studies assessing the impact of periodized RT on maximal strength (10, 17, 29), functional capacity, body composition, and inflammatory biomarkers (29) across 12 (17), 16 (29) and 18 (10) weeks. Yet, despite the distinct variation in the training structures implemented, similar changes in outcome measures among the various models were reported. However, it is proposed that longer-term training periods (>18 weeks) may augment program differentiation and increase the likelihood of observing any potential superiority of periodized RT. To-date, only one study has study has evaluated the long-term effects of periodized RT in older adults (16). Specifically, 25 weeks of NP and DUP RT induced similarly significant improvements in body composition, strength, and reductions in HR and perceived exertion during ADL. However, a greater ES was noted for the reduction in perceived exertion during ADL performance following DUP (0.6) versus NP RT (0.1). Therefore, research should continue to assess the impact of periodized RT on key neuromuscular, physiological and health-related outcomes in the aging population, thus providing a greater understanding of periodization strategies in counteracting the detrimental effects of sarcopenia.

Therefore, the purpose of this study was to compare the effect of periodized (specifically BP and DUP) versus NP RT on physical function and health outcomes in older adults over a 22-week intervention. It was hypothesized that periodized RT would produce greater improvements in outcome measures than NP RT.

METHODS

Subjects

Forty one-older healthy older adults were recruited for the present study (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg). Sample size estimation was based upon DEXA outcome measures during previous RT interventions of similar duration among older adults (16, 22), which displayed the most conservative ES among measures used in our study. An ES of 0.28 with a power of 80% at an alpha level of 0.05 produced a total sample size of thirty-six, based on a repeated-measures, within-between ANOVA model (G*Power 3.1 software).

All subjects provided medical clearance from their personal physician and completed a health history questionnaire. Exclusion criteria included lactose intolerance, a BMI of ≥ 30 $kg{\cdot}m^2$, any prescribed medication that could confound data, i.e. testosterone, corticosteroids, any pre-existing musculoskeletal, cardiovascular or neurological condition, or any other condition considered to cause risk to the subjects through RT or reduce their ability to adapt. Additionally, subjects were untrained, i.e. had not participated in structured exercise training designed to improve physical fitness over the previous 12 months. Finally, subjects were instructed to continue with every day normal activities and discouraged from engaging in any unaccustomed activity. The University Human Research Ethics Committee approved the study and subjects were fully informed of the nature and possible risks of all procedures before providing written informed consent.

Experimental Design

The present study employed a 3 (groups) x 3 (time-points) between-/within-subjects design, with a total duration of 31 weeks, comprising 2 familiarization sessions, a 4-week control period, a 22-week RT period, and the completion of all testing procedures. Subjects completed test protocols in weeks 2, 7 and week 31, using identical protocols. Weeks 3-6 were a control period to ensure reliability of baseline measures, during which time no RT was performed, and subjects simply maintained their normal recreational physical activities. Thereafter, subjects commenced a 22-week by 3 $d \cdot wk^{-1}$ RT intervention, excluding weeks 22, 25 and 28 where subjects trained 1 $d \cdot wk^{-1}$. These weeks were transition weeks and were modified ad hoc due to observing signs of overtraining in some subjects, therefore the aim was to promote recovery and reduce the potential for injury or illness. Furthermore, no RT was performed during week 19 for the completion of testing procedures at the mid-training time-point (data not included in the present study), and continued as normal in week 20. Therefore, the total number of prescribed training sessions over the training intervention was 60. Furthermore, subjects were randomly stratified into the three experimental RT groups (NP, BP and DUP) based on gender, age, body mass index (BMI), and strength (peak isometric torque of the right knee extensors). A visual depiction of the experimental design is provided in Figure 1.

Insert Figure 1

Testing Procedures

Subjects were fully familiarized and instructed in the proper execution of all testing protocols across two familiarization sessions to reduce the influence of any acute learning effects. Testing procedures were conducted using the same equipment at one location, by the same researcher across the study who was blinded to the subject’s training group assignment, and with participants being tested at a similar time of day to reduce the effect of any diurnal variations. At each testing time-point, subjects were required to visit the testing location on three days separated by approximately 48 h in order to complete all testing procedures.

Anthropometric Measures

Body mass was measured by a calibrated electronic scale (HW200, A&D Mercury Pty, Ltd, Thebarton, SA) to the nearest 100 g and height was determined with a wall-mounted stadiometer (Model 220, SECA, Hamburg, Germany) to the nearest millimeter. Waist-to-hip ratio (WHR) was calculated by measuring waist and hip circumferences using an anthropometric flexible steel tape measure (Lufkin W606PM). Waist circumference was measured at the approximate midpoint between the lower margin of the last palpable rib and the top of the iliac crest, and hip circumference was measured at the widest portion of the buttocks. All anthropometric measurements were completed with subjects wearing light clothing and no shoes.

Dual-energy X-ray absorptiometry (DEXA): Total body fat percentage (BF%), lean body mass, fat mass, bone mineral content (BMC) and bone mineral density (BMD) were derived using DEXA (Discovery A, Hologic, Inc., Waltham, MA). Subject's legs were secured using non-elastic straps to prevent movement during the measurement. Quality assurance tests were run daily in accordance with standard operating procedures

Physiological Measures

Blood Samples: Resting venous blood samples were collected from a superficial arm vein on the radial aspect of the arm using a needle and vacutainer following a 12 h overnight fast. Subjects were instructed to accurately log their dietary intake the day before the first blood sample was collected, which then served as a written record in order to replicate during the day before future blood samples for standardization. One 5 mL S.S.T vacutainer was collected and centrifuged for 10 min at 12,000g and stored at −80°C. At the end of the study, blood samples were analyzed for blood lipids (total cholesterol, HDL and LDL cholesterol, and triglycerides) and high-sensitivity c-reactive protein (CRP).

Blood Pressure: Resting blood pressure was measured by a digital blood pressure monitor (Intelli Sense, Omron Healthcare, Australia) following a 5 min period of sitting quietly succeeding blood sample collection.

Physical Function

<u>*Maximal Neuromuscular Strength:*</u> An isokinetic dynamometer (Biodex System 3 Pro, Ronkonkoma, NY) was used to measure peak isometric torque (Nm) of the right knee extensors. Subjects were seated with the thigh and trunk secured to the device for all test protocols. The hip and knee angles were 110° and 120°, respectively (180° refers to full extension). Subjects performed one 3 s submaximal contraction at 50% of perceived maximal intensity. Following 1 min of rest, subjects performed a maximal voluntary isometric contraction (MVIC) for 3 s, with 1 min rest between three separate repetitions. If any countermovement was evident or if peak torque differed by >5% among attempts, a further repetition was performed. The force signal was recorded on a computer and analyzed using LabChart software (PowerLab System, ADInstruments, NSW, Australia), with the highest measure included in statistical analyses.

Maximal muscle strength was measured for chest press and leg press exercises using the one repetition maximum (1RM) method. Subjects performed two submaximal sets of eight repetitions at 50% of the predicted 1RM, with 1 min rest between sets. Multiple 1RM contractions were then performed with the load increased progressively, aiming to establish 1RM within 3-5 efforts and with 3 min rest between attempts. The 1RM was recorded as the maximum weight that participants were able to move through a full range of motion without change in body position other than that dictated by the specific exercise motion.

<u>*Repeated chair rise:*</u> Subjects were seated in a hard-backed chair 43 cm from the floor, with arms folded across their chest. The instruction to rise as fast as possible to a full standing position and then return to a full sitting position five times was provided. The time to complete the test was recorded to the nearest tenth of a second using a hand-held stopwatch.

<u>*Stair climbing:*</u> Subjects climbed one flight of stairs (11 stairs per flight, 16 cm rise per

stair) as rapidly as they could safely manage without the use of the handrails and making contact with all of the steps. The time to complete this task was recorded to the nearest hundredth of a second using custom-built portable timing mats connected to a hand-held, electronic timer device (Industrial Equipment & Control, Melbourne, Australia).

Both the repeated chair rise and stair climbing protocols were performed in triplicate, with 1 min recovery allowed between attempts, and the mean time of all trials included in statistical analyses. The coefficient of variation for the repeated chair rise and stair climbing protocols was previously reported as 5.6% and 4.9%, respectively, among a similar population (14).

Quality of Life and Balance Assessment

Subject’s functional health and well-being, i.e. health-related QOL, was obtained via the SF-36v2 Health Survey (SF-36v2) (QualityMetric, USA) (40). Additionally, the Activities-Specific Balance Confidence (ABC) Scale was completed to assess balance confidence during everyday activities in and outside of the home (28).

Physical Activity and Dietary Intake Standardization

Subjects were encouraged to maintain their habitual physical activity pattern and dietary intake throughout the study. Physical activity was assessed via the CHAMPS Physical Activity Questionnaire for Older Adults (University of California, USA) (15). Dietary intake was assessed using a 3 day weighed food diary, recorded by subjects during the week prior to testing weeks, and assessed for any significant changes in energy intake and macronutrient profile using FoodWorks 7 software (Xyris, QLD) and the AUSNUT 2007 database of Australian foods. Specifically, dietary intake was recorded on the same days throughout the study, however this was across three non-training days during weeks 1 and 6, and two “normal” days and one training day during week 30.

Resistance Training

All exercises were executed on RT machines (Cybex, MA, USA) with zero use of free weights. The resistance and repetitions performed in the work-sets for each exercise were recorded in a training log and served as a written record for subjects at the start of training sessions. Subjects were fully familiarized with all machines prior to commencing the training intervention. Furthermore, training sessions were performed at a regular time of day, with a minimum of 48 h between sessions, and were supervised by exercise science bachelor degree qualified instructors to ensure proper exercise technique and reduce the risk of injury.

All training sessions commenced with a 5 min standardized warm-up consisting of light stationary cycling, rowing or brisk walking on an ergometer or treadmill (Technogym, London, UK). Resistance exercise selection remained the same across the study and was identical between all training groups, targeting concentric and eccentric muscle actions of major muscle groups and with lower-body and upper-body exercises alternated. Specifically, exercises included; seated leg press, lat pull-down, seated leg-curl, chest press, leg extension and seated row. A warm-up set of each exercise was completed at approximately 50% of the resistance of the first work-set. In order to provide recovery, a rest interval of 1 min was provided between the warm-up set and the first work-set, and a 1.5-2 min recovery period was employed between consecutive work-sets. Subjects were instructed to perform the concentric portion of exercises with maximal velocity to promote optimal neuromuscular adaptation and functional performance (7), and control the eccentric portion using a 2 s cadence as monitored by trainers.

Exercise resistance was prescribed using repetition maximum (RM) sets to ensure that the resistance stimulus was progressive to accommodate strength adaptations, requiring adjustment of the exercise resistance to ensure momentary muscular concentric failure (i.e. inability to complete a repetition in a full range of motion due to fatigue) at the prescribed

RM target. At no point did subjects continue performing repetitions above the required RM target, yet the resistance was increased as necessary in 1.25, 2.5 or 5kg increments, depending on the absolute resistance. However, if a subject failed to complete the required number of repetitions, the number performed was recorded and the resistance was reduced accordingly for any remaining sets. Instructors initially led this careful adjustment of exercise resistance based on visual cues of exertion and by asking subjects how difficult they perceived work-sets. Once subjects were competent in ensuring muscular failure at the required RM target, instructors simply prescribed the resistance of the first work-set for each exercise based on the training log records and then observed to ensure this was modified accordingly.

The RM targets prescribed for each group across the intervention is outlined in Table 1. The training focus for each RM target was; 15RM = strength-endurance, 10RM = hypertrophy, and 5RM = maximal strength (2). The training intervention is displayed in blocks of training (mesocycles) to clearly outline the BP program. Traditionally each training block includes several complete weeks (microcycles), however training blocks in the current study comprised 11 total training sessions due to scheduling constraints, specifically three complete microcycles plus two sessions within the following week. Overall, BP and DUP groups completed the same number of training sessions at each RM target. Moreover, as differences in the overall training volume between RT programs have been proposed to influence performance (11), total repetitions were equalized between training groups in order to reduce potential confounding factors, thereby allowing the sole examination of the effect of program structure on outcome measures. Therefore, the only difference between DUP and BP was the time and sequence of the load application. Furthermore, to check for any differences in workload between training groups across training blocks and the total training period, volume load (VL) (number of sets x number of repetitions x weight lifted (kg)) was calculated.

Insert Table 1

Protein Supplementation

On completion of each training session each subject ingested a standard liquid whey protein supplement mixed with 200 ml of water according to current recommendations (4). Each 30 g serving contained 498 kJ, 24.1 g protein, 1.7 g total fat, 1.1 g saturated fat, 1.4 g total carbohydrate of which 1.4 g was sugars, and 42.6 mg sodium.

Statistical Analyses

Data were analyzed using SPSS statistical software (SPSS Inc., Version 22, NY, USA). Normality of distribution was assessed using the Shapiro-Wilk statistic and where data was not normally distributed ($p<0.05$), log transformation procedures were applied with data re-checked for normality before applying parametric tests.

To validate the random stratification of subjects, a one-way analysis of variance (ANOVA) was used to check for between-group differences in baseline demographics and peak isometric torque. This analysis was also conducted on VL and repetitions performed across each training block and the total training period.

To check for any changes in outcome measures across the control period (pre-control to baseline), a group x time (3 x 2) repeated measures ANOVA was used to assess main effects for time and group x time interactions. A separate 3 x 2 repeated measures ANOVA was performed on outcome measures across the training period (baseline to post-intervention). Furthermore, an analysis of covariance (ANCOVA) was used to analyze between-group differences in the absolute change of outcome measures (i.e. post-intervention – baseline) including baseline data as the covariate. To examine any gender effects, a separate ANCOVA was performed on absolute change data including gender as the independent variable and baseline data as the covariate. When required, Tukey's test was used for post-hoc analyses.

Data are presented as mean ± SD, with 95% confidence intervals (CI) and Cohen's *d* within-group ES calculated for the main outcome measures using the pooled SD, with an ES of 0.2, 0.5 and 0.8 representing small, moderate, and large differences, respectively. Finally, post-hoc power analyses were calculated for outcome measures using the final sample size, at an alpha level of 0.05 and based on a repeated-measures, within-between ANOVA model (G*Power 3.1 software). Statistical significance was set at $p<0.05$ for all analyses.

RESULTS

Unfortunately, one subject experienced an unforeseen accident and did not commence RT, and one subject dropped out in week 1 feeling unable to complete the training requirements. Additionally, there were six further dropouts over the course of the intervention due to injury or illness (NP=2; BP=1; DUP=3), with three injury cases relating directly to the study (NP = 1; BP = 1; DUP = 1). Specifically, two subjects experienced a minor muscle tear during 1RM procedures and one subject suffered an overuse injury. No other adverse events occurred during RT or testing procedures. Therefore, a total of thirty-three subjects completed the study (female=17, male=16; 71.3 ± 5.4 y; 166.3 ± 8.5 cm; 72.5 ± 13.7 kg), with only these data included in analyses based on a per-protocol approach.

Subjects' demographics at baseline and post-training are presented in Table 2, with no between- or within-group differences noted ($p>0.05$). Total fat mass was the only measure to demonstrate a gender effect ($p=0.025$), therefore data are presented for the entire training group for all other outcome measures to optimize statistical power.

Insert Table 2

Resistance Training

An adherence rate of ≥85% to RT was achieved by all subjects with no between-group differences ($p=0.513$) (NP = 95.6%; BP = 96.9%; DUP = 96.8%). Between-group differences in mean VL and repetitions performed across training blocks are presented in Figure 2. However, the group mean total VL was not statistically different between-groups (*p*=0.620) (NP = 514,104 ± 149,938 kg; BP = 495,559 ± 128,169 kg; DUP = 554,068 ± 151,897 kg), which was also true for group mean total repetitions performed (*p*=0.193) (NP = 13,287 ± 579; BP = 13,675 ± 354; DUP = 13,609 ± 619), respectively.

Insert Figure 2

Outcome Measures

Control Period

There was a significant main effect for time for total cholesterol (*p*=0.047), triglycerides (*p*=0.020) and repeated chair rise performance (*p*<0.001) across the control period, with no significant interactions or between-group differences noted (*p*>0.05). Total cholesterol significantly increased from 5.71 ± 0.64 to 5.98 ± 0.64 mmol/L (ES=0.42), 5.83 ± 0.88 to 6.05 ± 1.00 mmol/L (ES=0.23) and 5.04 ± 0.97 to 5.20 ± 1.42 mmol/L (ES=0.13), for NP, BP and DUP groups, respectively. Similarly, triglycerides significantly increased from 1.07 ± 0.24 to 1.30 ± 0.45 mmol/L (ES=0.64) for NP, 0.92 ± 0.28 to 0.97 ± 0.26 mmol/L for BP (ES=0.19), and 1.10 ± 0.51 to 1.15 ± 0.44 mmol/L (ES=0.10) for DUP. Finally, there was a significant reduction in the mean time for completing the repeated chair rise test, specifically 10.32 ± 1.37 to 9.70 ± 1.02 s (ES=0.51), 10.78 ± 1.89 to 10.12 ± 1.52 s (ES=0.38) and 9.87 ± 1.36 to 9.47 ± 0.99 s (ES=0.34), for NP, BP and DUP groups, respectively.

Body Composition, Anthropometric & Physiological Measures

Group mean ± SD, 95% CI and ES data for body composition, anthropometric (excluding height, BM and BMI) and physiological measures are presented in Tables 3 and 4, respectively. A significant main effect for time was evident for systolic blood pressure (*p*=0.034), total BF% (*p*<0.001), lean mass (*p*<0.001), fat mass (*p*<0.001) and HDL cholesterol ($p=0.039$). However, no significant interactions or between-group differences were evident ($p>0.05$). As noted, a significant gender effect was found for total fat mass ($p=0.025$) with a significantly greater reduction evident in males (-3.48 ± 1.94 kg, ES=0.30) versus females (-1.86 ± 2.13 kg, ES=0.12), baseline to post-training.

Insert Tables 3 and 4

Physical Function

Group mean ± SD, 95% CI and ES data for all physical function measures are presented in Table 4. A significant main effect for time ($p<0.001$) was noted for peak isometric torque, chest press and leg press 1RM, stair climbing and repeated chair rise performance. Furthermore, a significant interaction was found for chest press ($p=0.034$) and leg press ($p=0.009$) 1RM, but not peak isometric torque, stair climbing or repeated chair rise assessments ($p>0.05$). However, no between-group differences were detected for any physical function measures ($p>0.05$) based on ANCOVA.

Quality of Life and Balance Assessment

No main time effect or significant interactions for health-related QOL were noted, specifically physical and mental summary scores from the SF-36v2 ($p>0.05$) (Table 3). Also, a significant main time effect ($p=0.018$) on balance confidence was evident, however no significant interaction or between-group differences were noted ($p>0.05$).

Physical Activity and Dietary Intake Standardization

There was no significant interaction or main time effect for the frequency of total and moderate-intensity physical activity performed ($p>0.05$). In addition, dietary intake did not change significantly in the pooled data of the whole cohort for energy intake across the overall study period (7981.1 ± 1552.1 to 7847.8 ± 1992.8 kJ, 1.7%, ES=0.07). Furthermore, the % of energy derived from carbohydrate was statistically unchanged (p>0.05) (38.9 ± 7.2 to 40.3 ± 8.7 %, ES=0.17). However, the % of energy derived from protein significantly increased (p=0.007) (19.5 ± 4.3 to 21.2 ± 4.9 %, ES=0.37) and the % of energy derived from fat significantly decreased (p=0.029) (33.8 ± 6.4 to 31.1 ± 6.3 %, ES=0.43) for the entire cohort over the course of the study.

DISCUSSION

This study investigated the effect of 22 weeks of BP, DUP and NP RT on a comprehensive range of physical function and health outcomes in apparently healthy untrained older adults. Contrary to our original hypothesis that periodized RT would enhance training adaptations, all three training models were equally effective for promoting significant improvements in various physical function and physiological health outcomes through RT in this population.

In order to compare the impact of different RT models, it is essential to equalize the overall training volume at completion of training. If not, whether differences are due to the periodization structure, or simply greater accumulation of total training volume, is unknown. In contrast, it has been proposed that if the overall training volume and intensity is equal, similar rates of adaptation will occur despite the periodization model (3), supported by the present findings. In detail, NP, BP and DUP RT, regardless of differences in program structures (Figure 2), demonstrated an equally significant beneficial impact on several important physical function and health-related outcomes. Therefore, despite failing to detect an optimal training model, our data further support the considerable public health implications of RT for older adults. Overall, the present RT interventions were successful at improving systolic blood pressure (mean change for all groups, -3.2%), total BF% (-11.9%), fat mass (-11.1%), lean body mass (6.7%), HDL cholesterol (5.9%), peak isometric torque (15.1%), chest press (30.3%) and leg press (47.1%) 1RM, repeated chair rise (9.9%) and stair climbing (20.7%) performance, and balance confidence (2.3%) (Tables 3 and 4). This range of positive adaptation is considerable and collectively lowers the risk of chronic disease, while preserving independence and increasing QOL. Considering maximal strength improvements alone, based on annual strength reductions between 2.5-5% with advancing age (1, 12), the present 15.1% increase in peak isometric torque indicates counteracting ~3-6 years of age-related strength loss following only 22 weeks of RT. This rises to ~7-15 years when based on the average 38.7% improvement across chest press and leg press 1RM measures.

As noted, previous investigation of periodized RT in older adults is lacking, with few studies examining limited outcome measures in untrained subjects. Yet in agreement with the present findings, similar strength and body composition improvements have been previously reported between NP and DUP structures following 25 weeks of RT (16), and NP and BP RT across an 18-week training period (10). What's more, 12 weeks of traditional and undulating periodized RT produced comparable increases in lower-body strength and power in elderly men (17). Finally, 16 weeks of traditional and undulating periodized RT were found to be equally effective for leg press 1RM and functional capacity improvements among untrained elderly females (29). Therefore based on the current available evidence, it appears that RT periodization is not critical for optimizing physical function and physiological adaptations in untrained older adults.

The general adaptation syndrome is central to periodization theory, which states that if a system experiences a stressful bout of exercise, it will respond with a temporary decrease in performance followed by supercompensation. However, if the applied stress remains at the same magnitude (i.e. intensity, volume and frequency), the system will accommodate to this stress and adaptations will plateau. Consequently, training programs are often organized to routinely provide a novel stimulus, thereby promoting continued adaptations. Considering this, it is important to acknowledge the inclusion of untrained subjects in the present and previous studies examining periodization in older adults. Based upon the emerging evidence that regular performance of RT can attenuate the hypertrophic response (33), increasing muscle mass may become more difficult over time, subsequently hindering performance improvements. Thus, more advanced RT protocols such as structured periodization of increasingly heavier loads or greater time under tension (TUT) may be necessary to elicit meaningful adaptations to RT in trained individuals. Also, based upon the idea that initial strength adaptations are predominantly due to enhanced neural activation and coordination, more advanced RT may be required for continued adaptation once these basic motor skills are acquired (19). However, recent evidence highlighting significant improvements in muscular hypertrophy following only 9 weeks (18 sessions) of RT in older adults (20) challenges this notion. Nevertheless, the present 22-week training period was possibly too brief to observe any advantage of periodized RT, and consequently NP, BP and DUP RT provided a similar novel training stimulus across the untrained cohort. Therefore, whether periodized RT strategies enhance training adaptations in older adults with at least one year of consistent RT experience warrants examination.

However, despite no statistical between-group differences noted in outcome measures following RT, there are some distinctions worth noting based on ES data. First, the largest ES for improvements in isometric and dynamic (1RM) strength were apparent in BP (Table 4). Yet, as strength improvements following RT are the result of motor learning as well as physiologic changes in muscle, and as BP performed an intensified block of 5RM immediately prior to post-intervention testing, subjects were ultimately practicing the specific motor schema associated with lifting heavier loads and greater force production. Therefore, larger strength improvements resulting from BP are not surprising and highlight the neuromuscular specificity of training. Also, while such ‘peaking’ may be critical in sport performance, i.e. prior to major competition, this is less relevant in a health and wellness setting. Nevertheless, considering that strength has been shown to be more important than quantity in estimating mortality risk (25), future studies should include more routine strength assessments across RT interventions in order to confirm this.

Similarly, the ES for improvements in balance confidence was also greatest in BP (0.66), followed by NP (0.38) and DUP (0.07), suggesting a possible association with maximal strength. Yet this pattern was not observed for the significant increase in functional capacity measures, with the greatest magnitude of effect noted in NP>DUP>BP. Such disparity between the impact of RT models on strength, balance and functional abilities proposes that factors other than maximal strength likely influence functional capacity among older adults. For instance, power is postulated as a greater indicator of functional status than strength, and a positive association between RT-induced power adaptations and ADL performance has been highlighted among the elderly (5, 6). However, due to the exclusion of power measures in the present study, further research is required to confirm the impact of periodized and NP RT models on neuromuscular abilities along the entire force-velocity curve in the aging population.

Further, the reduction in triglycerides differed among groups, with an ES of 0.57, 0.22 and 0.00 for DUP, NP and BP groups, respectively, thus suggesting that daily manipulation of the training stimulus may be most preferable for improvements in blood lipids. Finally, there was a moderate, borderline large ES for the reduction in systolic blood pressure (0.77) following NP RT, with a non-meaningful effect noted in BP and DUP (Table 3). Consequently, NP, BP and DUP models may all hold promise in improving different aspects of health and physical function, and further investigation may lead to the recommendation of an appropriate RT model based upon the specific outcome(s) desired. As noted, whether such between-group differences would increase in magnitude among experienced lifters remains unknown.

It has been proposed that implementing brief, simple, feasible and efficacious RT interventions with emphasis on long-term adherence should be prioritized in a public health setting, with subtle differences in strength gains resulting from complex RT protocols less critical (27). The application of basic periodization strategies may therefore be advantageous via better management of training monotony, which likely enhances the enjoyment of and tolerance to RT, ultimately aiding long-term adherence. On the other hand, loads equivalent to 90% and 30% of 1RM lifted to momentary muscular concentric failure were reported to produce similar acute increments in protein synthesis (9). Therefore, based upon the size principle, the degree of motor unit activation achieved during RT may consequently be considered more important than the external load. What's more, a recent meta-analysis concluded that RT using low loads ≤60% 1RM promotes substantial increases in strength and hypertrophy among untrained individuals (34). Therefore, RT involving lifting low loads to muscular failure may offer a simplistic and feasible training model for the aging population, particularly when aiming to optimize adherence under minimal supervision (27).

However, as persistently training to muscular failure is suggested to increase the potential for overtraining and psychological burnout (13), and likely caused the signs of overtraining observed in the present study, the safety and sustainability of this approachable is questionable. Also, although loads ≤60% 1RM were found to induce considerable training adaptations, there was a trend for the superiority of higher loads (≥65% 1RM) on both strength and hypertrophy, with relatively short training durations (6-13 weeks) in the small number of studies included acknowledged as limitations (34). Also, whether loads ≤60% 1RM promote continued adaptation once a training base is established is unknown. Nevertheless, the minimal effective dose of heavier loads necessary for optimizing training adaptations in older adults requires examination. For instance, 'heavier' loads ~65% 1RM may be sufficient, rather than 5RM loads (~87% 1RM) as prescribed in the current study.

Yet, above all, due to such drastically low participation rates reported among the elderly (21), educating this population on the vast benefits of RT and engaging them in any type of regular training is significant. Accessibility and affordability of RT is also critical, where these factors should be the primary focus prior to examining the finer aspects of program design. Also, despite ACSM providing clear and concise recommendations for RT in older adults (30), it seems the public health message of 'move more, sit less' is most commonly endorsed. Obviously performing any regularly physical activity (walking, swimming, cycling) is beneficial compared to a sedentary lifestyle, but perhaps an increased effort to specifically promote RT is required, particularly when a large portion of the aged population are likely completely unaccustomed to lifting weights.

As the control period was used to ensure reliability of baseline measures, it is important to acknowledge the statistical change in measures during this 4-week period of no RT. Despite familiarization sessions, the significant improvement in repeated chair rise performance was likely due to practice of the protocol. Yet, the magnitude of effect across the control period (NP=0.51, BP=0.38, DUP=0.34) was minute in contrast to that observed post-RT (NP=2.56, BP=1.21, DUP=1.91). Therefore, the improvement in function following RT was considered to be a direct result of the intervention. Additionally, the ES for the increase in total cholesterol was moderate for NP (0.42), and small for BP (0.23) and DUP (0.13) following the control period, with this pattern also evident for the increase in triglycerides (ES; NP=0.64, BP=0.19 and DUP=0.10). Although subject's dietary intake was statistically unchanged during this period based on the 3 day weighed food dietary analyses, many subjects commented that during the control period they were enjoying their "final few weeks of freedom" before embarking on 22 weeks of RT. Therefore, it is questioned whether additional foods and drinks were consumed but unreported in the dietary analysis, which may have influenced such blood biomarker results. However, as body composition indices remained unchanged during this time, this remains speculative and highlights the limitation of self-reported dietary intake.

Finally, as noted, thirty-three subjects fulfilled all study requirements and were included in the final analyses, however this did not satisfy the a priori sample size estimate of thirty-six subjects. Therefore, the present sample size is a potential limitation and it could be argued that between-group statistical differences were possibly undetected due to type II error. It is recommend that future long-term training studies recruit an adequate cohort to ensure sufficient statistical power, considering the present dropout rate of 19.5%.

In summary, NP, BP and DUP RT models are equally effective for promoting significant improvements in various physical function and physiological health outcomes in apparently healthy untrained older adults. Consequently, periodization strategies do not appear to be necessary during the initial stages of RT in aging individuals. The present data support the considerable public health implications of RT, ultimately lowering the risk of chronic disease, while preserving independence and increasing QOL. The impact of periodization strategies on neuromuscular abilities along the entire force-velocity curve, in previously trained older adults, and on long-term enjoyment, tolerance, and adherence remains unknown. Practitioners should work towards increasing RT participation among older adults via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings.

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FIGURES

Figure 1. A visual depiction of the experimental design including familiarization, all testing procedures and a 22-week resistance training (RT) intervention.

Figure 2. Group mean A) total volume load (VL) and B) repetitions performed, across training blocks. * Signifies statistically different from both other groups, and $^{\#}$ indicates statistically different from NP ($p<0.05$).