2019-03-15

Optimal Approach to Load Progressions during Strength Training in Older Adults: An Intent-to Treat Study

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OPTIMAL APPROACH TO LOAD PROGRESSIONS DURING STRENGTH TRAINING IN OLDER ADULTS: AN INTENT-TO TREAT STUDY

By

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A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

May 2019

UNIVERSITY OF MIAMI

A dissertation submitted in partial fulfillment of
the requirements for the degree of
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Optimal Approach to Load Progressions during Strength Training in Older Adults: An Intent-to-Treat Study (May 2019)

Abstract of a dissertation at the University of Miami.

Dissertation supervised by Professor Joseph Signorile.
No. of pages in text. (56)

Regular participation in structured resistance training (RT) is one of the most effective interventions an individual can engage in to counter the progressive decline in muscle mass and physical function associated with normal aging. Researchers agree on the need for RT programs to progress at an appropriate speed, neither too slow to optimize compliance, nor too quickly to increase soreness and injury risk, however there is no consensus concerning the best method to use in an older population. The objective of this investigation was to compare three common and one unique progression models to determine if an optimal method exists for use with older adults. 83 healthy community-dwelling older adults (71.8 $\pm$ 6.2 y) performed 9 weeks of structured RT (2.5 days/week) after a common two-week familiarization period designed to introduce the subjects to the exercise machines and allow collection of baseline measures. Treatment groups were identical except for the method used to determine increases in training loads. Multiple analyses of covariance (ANCOVA; controlling for baseline values) indicated no significant between-group differences on any maximal strength (chest press 1RM; leg press 1RM) or functional performance outcome (usual walking speed, maximum walking speed, 8 foot timed up-and-go, gallon jug transfer test, 30 second sit-to-stand). Results showed rating of perceived exertion (RPE) group found the progression to be significantly more tolerable and enjoyable than subjects in the repetitions in reserve (RiR), repetition maximum (RM), or percentage of one repetition max (%1RM groups) group. Given no significant differences were identified between the RM, RPE, %1RM, or RPE methods with respect to strength gain or functional performance, we conclude the RPE method is the best RT progression method to use for older adults because it is likely to be perceived as the most tolerable and enjoyable, which are two important factors determining older adults' continued participation in RT. Future researchers are directed to consider whether exercisers previous RT experience and personality factors influence which method is most appropriate to use.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude for the guidance provided by my mentor and advisor, Dr. Joseph Signorile, without whom this project would not have come to fruition. I am similarly grateful to my committee members, Drs. Jacobs, Eltoukhy, and Zopluoglu, for their tireless efforts during all stages of this dissertation and for their valuable feedback during the proposal and manuscript drafting stages. The quality of this study is infinitely greater for your efforts.

I would also like to thank my family members for their unwavering support over these last five years in Miami. Though you are far away geographically, your warm and encouraging presence has always felt close. To my friend and colleague, Mike Letter, it's been one heck of a journey and I can't imagine doing it without you. To my first mentor, Barry Legh, who first send me on my journey south for graduate studies, you have been a constant source of inspiration and who's helpful guidance has helped shape my career path as much as anybody. Thank you as well to the University of Miami, specifically the School of Education and Human Development and the Laboratory for Neuromuscular Research and Active Aging, for without your financial and material support, this dissertation would not have been possible. Lastly, a big thank you to the army of undergraduate assistants who helped with data collection. Without you there is no way I could have managed to oversee the nearly 3000 subject/hours involved with completing this project.

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CHAPTER 1: INTRODUCTION

It is well-documented that normal aging in humans is accompanied by a progressive decline in muscle mass and physical function[1], which can lead to a reduced quality of life and the inability to live independently.[2-4] Accordingly, interventions aimed at countering the negative effects of aging are of high priority to researchers and to date, no intervention has been found to be as effective than regular resistance training (RT).[5,6] While the benefits of RT in older adults are myriad and well-understood, ambiguity exists with respect to its optimal application; particularly in terms of frequency (number of training sessions per week), intensity (magnitude of loads that are used), volume (number of sets and repetitions that are completed in a given training session).[7] Part of the reason why optimal RT parameters for older adults remain elusive is a wide variety of training characteristics have been shown to be effective in improving important outcome variables for older adults, such as muscular strength and power.[3,7,8] For example, both training frequencies of 1 day per week and 3 days per week have been shown to be effective at increasing older adults' maximum strength level[9,10] as have high (80% 1RM) and low (50% 1RM) intensity loading patterns.[11,12]

One particularly-unclear aspect of optimal RT for older adults is the best way to increase training loads over the course of a multi-week training program to ensure increases in participants' strength level are matched with a concomitant increase in the loads they are lifting. Appropriate progressions are important to consider, given that bodies will cease to adapt to an exercise stimulus if its intensity is not periodically increased.[13] To date, four dominant approaches have been used by researchers to monitor increases in training loads during studies involving RT for older adults. While clear and compelling evidence exists in support of each of these four models, so does a coherent rationale as to why they should be avoided. The repetitions-to-failure method, for example, has been suggested as optimal for older adults by some researchers[14] because they believe it imparts greater physiological strain to the exerciser than do other methods; however, other researchers have suggested failure training is unnecessary and more likely to cause post-exercise soreness and discomfort.[7,14,15] To date, no study has directly compared the benefits and risks of the common progression models used in older adults' RT programs.

Literature Review

Progression and enjoyment are two critical factors to consider when designing a RT program for an older adult.[6,16] This is because programs that progress too slowly (either in intensity or volume) are unlikely to maximize the individual's potential for positive adaptation, programs that progress too quickly are likely to lead to overtraining and burnout, and programs that are not enjoyable are unlikely to be adhered to.[3] Accordingly, the ideal progression model for use with an older adult is one in which there is a smooth increase in loading intensity (that occurs in concert with increases in muscular strength) that is neither too slow to remain interesting nor too fast to remain enjoyable. While the need for appropriate strength training progressions in older adults' RT is well understood, consensus does not yet appear to exist among researchers as to the best method to utilize.[2]

Repetition maximum (RM) / Repetitions to failure method

Dr. Thomas Delorme laid the conceptual foundation for the repetition maximum (RM) method in 1945 with his seminal paper *Restoration of Muscle Power by Heavy*

Resistance Training.[17] In subsequent years researchers have varied somewhat in their application of the method; however, the underlying principle has always been the same: training loads are increased when an individual is able to complete a target number of repetitions (e.g. 10) with a given load without assistance or excessive rest between repetitions.[3] The most common way the RM method varies in practice is in the number of repetitions that constitute the 'repetition target', the number of consecutive sets in which the repetition target must be attained, and the number of consecutive training sessions in which the repetition target is achieved.[2,18-21] Support for the primacy of the RM method in older adults comes from the frequency with which it is utilized in relevant research,[3,22,23] and from the fact that it is the method advocated by the American College of Sports Medicine in their position stands on progression models for healthy adults[16] and strength training for older adults.[6]

Despite strong evidence in support of the RM method for older adults, substantial literature also exists outlining why the method should be avoided in this population.[15,24] The most significant criticism of the RM method in older adults is that it requires participants to train to 'failure', which typically occurs initially during the concentric (upward) phase when working muscles cannot produce enough torque to overcome the force of gravity against a given load beyond a critical joint angle or sticking region.[25-27] The theory that failure training will lead to greater strength gains than non-failure training is commonly attributed to Arthur Jones (founder of Nautilus exercise machines)[14], who's general rational was failure training causes greater motor unit recruitment and fiber activation, which are two key stimuli related to muscular adaptation after a period of structured RT.[14,25]

Contrary to the rationale originally laid out by Arthur Jones, abundant evidence exists to suggest failure training is not necessary to achieve full motor unit activation.[14] Sundstrep et al.[28], for example, demonstrated in a cohort of 15 untrained female subjects that full motor unit activation could be achieved in the abductor muscles of the upper arm by stopping exercise 3-5 repetitions before failure. These results, coupled with the fact that failure training often involves higher perceived effort and post-exercise discomfort in untrained individuals[3,14,29], appear to indicate the need for more research before the RM method can be confidently advocated as optimal for older adults.

Percent 1RM method

The percent one-repetition maximum (%1RM) method involves assignment of training loads based on the exerciser's maximum strength level in a given exercise.[30] Typical prescription, for example, might be to perform eight bench press repetitions at 70% of a person's one-repetition maximum (1RM). This means that an individual with a maximum bench press of 100kg would use a working load of 70kg. The method is commonly used in sport-performance training for athletes[30,31] and has particular utility in the design of RT programs targeted at a specific type of muscular adaptation (i.e. hypertrophy, strength, power, and endurance).[30] It has been established, for example, that enhancements in muscular endurance are best attained through high volume, low-moderate intensity programs (e.g. 20 repetitions with 50% 1RM), enhancements in muscular hypertrophy are best obtained through high-moderate volume, moderate intensity programs (e.g. 12 repetitions with 65% 1RM), enhancements in muscular strength are best obtained through low-moderate volume, high-moderate intensity programs (e.g. 6 repetitions with 85% 1RM), and enhancements in muscular power best obtained over a wide variety of intensities (30-90% 1RM) but with ample rest between efforts and always with the intent to move the load as quickly as possible.[30,31]

In addition to being prevalent in research involving high-performance athletes, extensive literature exists detailing the use of the %1RM method in RT programs designed for older adults.[2,32-35] The main reason why the %1RM method has been theorized as optimal for older adults is it may be the most effective at facilitating increases in maximal strength.[29] In a recent meta-analysis[29] looking at the effects of multimodal RT on frail older adults' maximal strength and functional capacity, researchers found substantially greater increases in maximal strength (standardized mean difference = 1.81 vs. 0.30) in studies using the %RM method compared to the ratings of perceived exertion (RPE) method. The authors speculated that the reason the %1RM was found to be so much more effective than the RPE method was that untrained older adults may have lower perceptions of intensity, which would lead to an under-estimation of the appropriate workload, which could potentially attenuate the degree of realized strength gains.

While a sound rationale and experimental foundation exists to suggest the %1RM method is optimal for older adults, several points of concern exist. The first is purely logistical: programming RT loads based on percentages of the 1RM entails periodic 1RM testing to account for the fact that the exerciser may be getting noticeably stronger from one week to the next.[2,7,36] This process can be tedious and time consuming[2,23], which is a concern for individuals working with a large group or for personal trainers who only have and hour or two with their client per week and must be sure that every session is perceived as both enjoyable and efficacious. For untrained individuals, the need to frequently re-establish 1RMs may be particularly laborious given that untrained individuals are known to experience particularly rapid strength gains in the early stages of a new RT program.[2,36]

A second reason why the %1RM method may not be ideal for older adults is that training with percentages of the 1RM may lead to an exercise stimulus separate from that which is intended (e.g. hypertrophy), since the traditional relationship between the 1RM and the total number of repetitions that can be completed is mutable over the course of a multi-week training period.[7,37,38] This means that a load that was appropriate for hypertrophy training in Week 1 of a training program may no longer be appropriate in week 5, because of the individual's strength gains.[36,37]

A third limitation to the use of the %1RM method in older adults is the fact that it is contingent on the accuracy of the initial value determined during 1RM testing.[24,36] Traditional 1RM testing methods are known to have poor reliability in inexperienced weight trainers[36,39-41] particularly in untrained older females.[36,41] Ploutz-Snyder and Giamis[41], for example, demonstrated that individuals may need up to 9 testing sessions before they produce consistent and reliable 1RM values. The inherent unreliability of 1RM testing in untrained individuals is problematic for RT in older adults as the method may lead to the under-estimation of subjects' true maximum strength level, which means that all subsequent training loads will be too low.[42]

An additional concern about the %1RM method is its intensity as a training experience[14,36,42], meaning individuals new to RT may be discouraged to participate further if they find the initial testing session too intense.[3,42] A final consideration about the use of the %1RM method in older adults is the potential for injury during 1RM testing. Concerns about 1RM testing in an elderly population stem primarily from two studies[43,44]; however, concerns regarding the author's testing methodology and operational definition of an injury have somewhat softened these results[45] and at present 1RM testing in older adults is an accepted scientific practice.[10,32-35,43,46]

Rating of Perceived Exertion (RPE) Method

The essence of the rating of perceived exertion (RPE) method is training loads are increased when an exerciser perceives a given load to fall below a predetermined level of difficulty.[47] An example of the application of the RPE method can be found in a recent article by Balachandran et al.[2] looking at high-velocity training parameters in a cohort of 38 older adults. Training loads were increased for a given exercise when subjects could perform all three sets of 12 repetitions at an RPE of less than seven out of ten points. The method has been extensively utilized in research related to RT in older adults[48-53], and the primary benefit of the RPE method is that it ensures all subjects complete each working set to the point of muscle fatigue but not failure, thereby reducing the risk of injury and/or muscle soreness.[2] Additionally, the RPE method may be ideal for use with older adults as it allows for adjustments to be made on an exerciser's working load for the day based on subjective feelings such as residual soreness or fatigue.[2,48] The reason why the RPE method is adaptable in this manner is rather than telling subjects to cease exercise when they complete a given number of repetitions (as in the RM and %RPE methods), exercisers are told to cease exercise when they perceive the exercise to have reached a pre-determined level of difficulty, regardless of the number of repetitions that have been completed.

As with the %1RM and RM methods, the potential benefits of using the RPE method with an older population must be balanced with its potential limitations. One of the limitations to the RPE method is that it requires exercisers to be familiar and experienced with both the scale that is being used to measure perceived exertion and with the somatosensory experience of maximal or near-maximal exertion in a resistance exercise[54], which may be particularly limiting when used with subjects who have neither. Additionally, when used with individuals experienced with RT, the RPE method may also be inappropriate as it has been shown that some individuals do not report maximal RPE values even when performing maximal repetitions to failure.[55-57] Lastly, the use of the RPE method in older adults may be limited as it requires significant documentation and program analysis: administrators (or exercisers themselves, if used in practice) must ask for and record subjects' RPE after each set and maintain a log over multiple sessions to determine when it is appropriate to increase the load for a given exercise.

Repetitions in Reserve (RiR) Method

The repetitions in reserve method (RiR) is the most recent of the four progression models presented in this study and is therefore supported by the smallest body of available literature. Despite this limitation, however, a sound rationale exists for its use in older adults. The RiR method is identical to the RM method with the key distinction that instead of performing each set until failure, subjects stop when they perceive they are only capable of performing one more repetition (have only one repetition 'in reserve').[24,54,58] Progressions are structured similarly to those used in the RM model: training loads are increased when subjects report having one or more 'repetitions in reserve' at the end of each prescribed set. The primary advantage of the RiR method is it eliminates the need for participants to train to the point of failure (the limitations of which have been previously discussed), while ensuring they closely approach it. As with the RPE approach, the RiR method may be ideal for older adults as it can account for variations in factors such as (e.g. sleep[59], nutrition[60], stress[61], recovery[37,38]) that may affect daily exercise performance.

A significant limitation to the use of the RiR method in older adults is the limited number of available studies on the topic[24,58] including a complete absence of research involving older adults. Also, similar to the RPE method, the utility of the RiR may be limited due to the fact it takes time for novice exercisers to gain familiarity with the scale being used, so they may be unable to detect when they truly have a single repetition left 'in reserve' before failure.[24,58] Until further research of the RiR method in older adults becomes available, the utility of the method will remain speculative.

Enjoyment and Perceived Tolerance

Unlike RT for sport-performance, where the ultimate value of a new method comes down to whether it evokes greater strength or power adaptations than existing methodologies, RT for older adults must consider a wider spectrum of outcomes.[3] This wider spectrum of outcomes includes to use RT as a medium through which a highly independent lifestyle can be maintained that is largely free of chronic disease.[3,16] This means that the determination of an optimal progression for older adults must incorporate factors such as enjoyment and perceived tolerance, since it would be pointless to advocate a highly-efficacious method that is either too boring or uncomfortable for many individuals to maintain. Additionally, an assessment of a subjects' enjoyment and perceived tolerance can aid in future investigations when two or more RT intervention strategies induce similar strength and functional performance improvements produce similar adaptations. A recent study by Conlon, Haff, Tufano, and Newton[3] provides a good example of how perceptions of enjoyment and exercise tolerance can be incorporated into studies. At the end of each training session participants' responses on a 7-point Likert scale to the following questions were recorded: "I have found the exercise session to be tolerable" and "I have found the exercise session enjoyable". While no significant between-group differences were identified with respect to average enjoyment levels and perceptions of tolerance, the article nonetheless presents a helpful framework to incorporate enjoyment and tolerance monitoring in future RT studies in older adults.

Adherence and Adverse Events

As mentioned, the value of any exercise intervention goes down dramatically if the population it is intended for is unwilling to utilize it. As such, program adherence is a commonly-used metric to compare the value of exercise interventions for older adults.[3,6] Similar to program adherence, frequency of adverse events is an important metric to consider when evaluating the merit of a RT program for older adults, as injuries resulting from physical conditioning have been shown to be an important deterrent to continuing an exercise regimen in older adults.[62] Despite the high value of information related to adverse events in older adults during RT, this parameter is under-reported in existing literature.[2] As reported by Balachandran et al.[2], of 123 identified studies involving RT trials in older adults, only 53 reported whether any adverse events had occurred.[63]

The study was designed to examine the efficacy, enjoyment, tolerance, adherence, and adverse event rate of four progression models used to monitor and adjust intensity progressions during the RT program. The purpose of this investigation was to compare three of the most commonly-utilized progression models for older adults to determine if an optimal method exists. A promising fourth model was also included that has yet to be studied in older adults, but is encouraging from a theoretical perspective. The methods were evaluated in terms of improvement in maximal strength, average working load across all exercise machines, adherence rates, and perceptions of exercise enjoyment and tolerance.

CHAPTER 2: METHODS

Design

A single-blinded, randomized-controlled design was utilized under a modified intent-to-treat analysis plan. All individuals who withdrew from the study were asked to return to the laboratory for post-testing, except those who withdrew for reasons unrelated to the study.

Participants

Potential subjects were recruited using flyers posted in the local community, a database of previous research subjects, and word of mouth. One hundred and fifty individuals expressed interest in participating and 87 were found to be eligible. A CONSORT chart detailing recruitment and flow of subjects through the study is detailed in Figure 1, and demographic statistics are presented on Table 1. Inclusion and exclusion criteria are detailed in Figure 2. Prior to enrollment, all subjects were given a thorough overview of the experiment and were provided the opportunity to ask any questions related to the research. They were also informed that they could withdraw from the study at any time for any reason without consequence. All participants signed an informed written consent form and all aspects of the study, including experimental protocol and intake documentation, were approved by the University's Subcommittee for the Use and Protection of Human Subjects. Participants were offered no compensation of any kind for their participation.

PRIMARY MEASURES

Changes in Maximal Muscular Strength

One Repetition Maximum

To measure changes in maximum muscular strength over the course of the study, participants performed an assessment of maximum upper and lower body strength known as a one repetition maximum (1RM) on the seated pneumatic chest and leg press.

Perceptual Markers of Perceived Tolerance and Exercise Enjoyment

Post-Exercise Survey

The session RPE was recorded for each participant 5-10 minutes after the workout session. Prior to departing, participants completed an anonymous session feedback form asking only their group number and placed it into a drop-box located near the exit to the gym. The session feedback form included two questions measured on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree) asking about session enjoyment ('*I have found the exercise session enjoyable*') and perceived tolerance ('*I have found the exercise session to be* tolerable').

SECONDARY MEASURES

Functional Performance Measures

Usual and Maximum Walking Speed

The usual and maximum walking speed tests involve repeated measurements over an 11m distance on a flat indoor surface and are widely reported in literature related to functional performance in older adults.[49,64-67] Usual walking speed in particular, has been used to verify functional limitations in daily life such as the ability to cross a street.[65] An

11m distance was marked on a straight walkway with marks 3 and 8 meters from the start line. Participants completed three trials spaced one minute apart: once at their usual walking speed and twice at their maximum walking speed. Walking speed was measured using a handheld stopwatch between the 3m and 8m marks. Usual walking speed was determined in the first trial and maximum walking speed was determined as the better performance of the second and third trials.

Timed Up-and-Go (TUG)

The 3m up-and-go is a test to assess dynamic balance, fall risk and agility. It has been shown to be well correlated to the Berg balance score (r=0.81), gait speed (r=0.6), and the Barthel index of ADL's (r=0.78).[2,68] A TUG score of 14s is sensitive (87%) and specific (87%) for identifying elderly individuals who are at risk for falls.[2,69] Participants were asked to stand up from a standard chair with a seat height of 43 cm, walk 3m as quickly as possible, turn around a cone, and then walk back to the chair and sit down. Time was recorded using a handheld stopwatch with the shorter time indicating better dynamic balance and agility. Two trials were performed with the lower score used.

Gallon Jug Shelf Transfer Test

The gallon-jug shelf-transfer test is designed to mimic an important activity of daily living- the transfer of a moderately heavy object. The test has been shown to be valid, reliable, and responsive in elderly population.[70] Each participant was asked to sequentially transfer five 1-gallon jugs as quickly as possible from a lower shelf, aligned with the base of the participant's patella, to a higher shelf placed at the level of the top of the participant's shoulder. Time was recorded using a handheld stopwatch. Two trials were provided with 1-minute of rest between trials.

30-Second Sit-to-Stand Test

The 30 second sit-to-stand test is designed assesses lower body strength and endurance in older adults. The test begins with the participant seated in the middle of the chair, back straight and feet flat on the floor. Arms were crossed at the wrists and held against the chest. On the signal "go" the participant rose to a full stand and then returned to a fully seated position. The participant was be encouraged to complete as many full stands as possible within 30s. After a demonstration by the tester, a practice trial of one to three repetitions was done to check for proper form, followed by one 30-s test trial. The score was the total number of stands executed correctly within 30s. If the participant was more than half-way through a stand at the end of 30s, it counted as a full stand.

Adverse Events

Weighted Adverse Events

Incidences of adverse events (AE) ranging from residual muscle soreness to muscle strain causing study dropout were monitored over the course of the study. To account for the fact that not all adverse events are of equal impact, a weighting system was utilized to give greater emphasis to more serious AEs. Incidences of residual muscle soreness with no reduction in training load were counted as one weighted adverse event (WAE) per session, AEs requiring a reduction in training load were counted as two WAEs per session, and AEs causing an exercise session to be postponed were counted as three WAEs. An AE causing the subject to drop out of the study completely was considered three WAEs plus one WAE for every training session left in the study. To our knowledge we are the first researchers to use a system of weighted adverse events.

Program Adherence

As mentioned, the value of any exercise intervention goes down dramatically if the population it is intended for is unwilling to utilize it. As such, program adherence is a commonly-used metric to compare the value of exercise interventions for older adults.[3,6] Dropout rates and frequency of missed sessions were evaluated to determine if significant differences existed between groups with respect to program adherence rates.

Testing Procedures

The study examined the efficacy, enjoyment, adherence, and adverse event rate of four common progression models used to monitor and adjust intensity progressions in older adults' RT aimed at increasing maximum muscular strength.

Baseline Testing / Familiarization Phase

Participants were assessed for two weeks before (pretest) and after (post-test) a 9 week structured RT that incorporated a two-week familiarization period. A detailed overview of the familiarization phase is presented in Figure 2.

Post-Testing

Participants returned between 5 and 14 days after completion of their final training session for post-testing on the same measures used in the baseline phase. Data were collected using the same methodology, minus the familiarization sessions.

Ratings of Perceived Exertion (RPE)

Ratings of perceived exertion (RPE) have been assessed for the overall body and the active muscles to track resistance training progressions and prescribe training intensities.[72] Considering the limited training background with resistance exercise in the study participants, the modified OMNI-resistance exercise scale (OMNI-RES)[73] was utilized and is provided in Figure 3. OMNI scales include mode specific pictorials, numerical ratings, and corresponding verbal descriptions that are distributed along an increasing intensity gradient thus making the scale easier to interpret.

Session Enjoyment and Perceived Tolerance

Prior to departing the laboratory after each exercise session, participants placed an anonymous session feedback form asking only their group number into a drop-box located near the exit to the gym. The session feedback form included two questions (7-point Likert scale; 1 = strongly disagree, 7 = strongly agree) asking about session enjoyment ('*I have found the exercise session enjoyable*') and perceived tolerance ('*I have found the exercise session to be* tolerable').

Adverse Effects Form

Reporting of adverse events used the same protocol and reporting forms as used in recent study[2] in our laboratory using a similar population. This reflects four types of events (falls, cardiovascular-related episodes, musculoskeletal-related events, and health care) suggested by the Behavior Change Consortium (BCC) of the NIH when reporting trial results for physical activity interventions.[56] Since most adverse events in resistance training studies are musculoskeletal in nature, we chose to further refine the classification of severity of musculoskeletal events as reported by the BCC. The adverse reporting form was be administered every four weeks.

Intervention

Eight pneumatic resistance exercise machines were used in this study (seated leg press, seated chest press, leg curl, adductor, seated row, lat pulldown, bicep curl, tricep press-down) and participants completed two training sessions per week in weeks 1-5 of the intervention period and three training sessions per week in weeks 6-9 of the intervention period. Aside from the method used to progress training loads, all characteristics of the training period were identical except for the fact participants in the %1RM group attended one extra session in week five to determine their 1RMs for possible increases to their training loads. The participants performed three sets of approximately seven repetitions on each machine before moving to the next exercise. A 1–2 min recovery was provided between sets and participants were instructed to perform the concentric phases of each exercise as fast as possible and to perform the eccentric (lowering) phase in a controlled (2 seconds) manner. Rest times, intensity, frequency and volume of training used in this study are all consistent with current recommendations for older adults American College of Sports Medicine.[16]

Repetition Maximum (RM) Group

Training loads for a given exercise were increased (5% upper body exercise, 10% lower body exercise) when the participant was able to complete three sets of seven repetitions using consecutive workouts without assistance, load reduction, or excessive between-rep rest. The starting load for each exercise was be the load used during the final familiarization workout.

Percent 1RM (%1RM) Group

Participants completed three sets of seven repetitions at 80% of their 1RM. Training loads were increased midway through the study after re-testing participants' 1RM in week 5. Participants were instructed to lower the resistance to ensure completion of 7 repetitions in any set they reached muscular failure before completion of 7 repetitions.

Ratings of Perceived Exertion (RPE) Group

Participants completed three sets of seven repetitions, starting with the load used in their final familiarization workout. After each set participants were asked to rate how difficult they perceived that set be using the previously discussed RPE scale. The scale was visible to participants at all times and training loads were increased for a given exercise (5% upper body exercise, 10% lower body exercise) when they reported an RPE of less than 8 after the third set on two consecutive days.

Repetitions in Reserve (RiR) Group

Participants were instructed to perform three sets of no more than seven repetitions and to stop when they felt they were only capable of performing one more repetition, or in other words, stop when they felt they had only one repetition left 'in reserve'. Training loads were increased for a given exercise (5% for upper body exercises, 10% for lower body exercises) when the participant could complete three sets of seven repetitions in this manner on consecutive workouts. The starting load for each exercise was the load used during the final familiarization workout.

Order of Exercises

In order to eliminate the possibly-confounding impact of metabolite build-up on the two main strength exercises, participants always completed the chest and leg press at the start of the exercise session. To accommodate multiple subjects training at the same time, however, the order of the remaining 6 exercises was allowed to vary although participants were instructed to alternate upper and lower body exercises whenever possible.

Warm Up and Cool Down

Each session began with one warm-up set on the leg press (6-8 repetitions at 50% initial working load) and warm-up set on the seated chest press (6-8 repetitions at 50% initial working load). Participants were also encouraged to partake in a 5 minute warm-up/cool-down on the treadmill/cycle ergometer prior to and after each training session; however, both were optional and left to the discretion of the subject.

Blinding

Subject blinding is a common practice in human subjects research and is often used to minimize rater bias, particularly when assessing subjective outcomes.[74] Pre and post-testing was conducted by two blinded assessors with no other involvement in the study. Data analyses was not be blinded.

Statistical Analysis

Baseline differences in age, BMI, training experience, leg press 1RM, and chest press 1RM were assessed using multiple one-way analyses of variance (ANOVA). Between-group differences in muscular strength and functional improvement over the course of the study were assessed using multiple one-way analyses of covariance (ANCOVA), controlling for pre-test values. Post-hoc pair-wise comparisons were conducted using a Bonferroni correction and, if necessary, non-parametric analysis used to address non-normal data distributions. Using G*Power, an estimated effect size (Cohen's *f*) of .45 was identified from an analysis of relevant previous literature. Under an alpha level of .025 (two-tailed), a required sample size of 68 was identified as necessary to obtain a statistical power of .80. Adjusting for an anticipated drop-out rate of 19%, 80 participants were identified as necessary (20 per group).

CHAPTER 3: RESULTS

Strength and Functional Measures

Demographic statistics by group and the complete sample are presented on Table 1. No significant between-group differences ($p < .05$) were found at baseline for any demographic, strength, or functional measure. Means ± SD, and results of significance testing for within-group changes in strength, enjoyment, tolerance, adverse events, and functional performance over the course of the study are presented on Table 2. The only significant between-group difference found for any strength or functional measure over the course of the study was improvement in average working load [$F(3,67) = 29.3$, $p \leq .001$, Cohen's $f = 1.52$]. Post-hoc testing revealed subjects in the RM and RiR groups had significantly higher average working loads at the end of the study than subjects in the %1RM [mean difference (SE) = 17.8 ± 2.1kg, $p \leq .001$; mean difference (SE) = 13.6 ± 2.1kg, $p \leq .001$, respectively] and RPE [mean difference (SE) = 12.1 ± 2.0kg, $p \leq .001$; mean difference (SE) = 8.0 ± 2.1kg, $p = .002$, respectively] groups. Comprehensive results of the ANCOVA for each variable are presented on Tables 3-10.

Adverse Events

No significant between-group differences were observed in the number of weighted adverse events over the course of the study. Group means (±SD) for the RiR, %1RM, RM, and RPE groups were 5.8 ± 8.7, 2.8 ± 3.7, 5.7 ± 7.7, and 2.3 ± 3.6, respectively. Comprehensive results of this analysis are presented on Table 11.

Enjoyment

Between-group differences in enjoyment were analyzed under a non-parametric model due to he lack of normality in the survey data (skewness = -1.8; kurtosis = 3.4). Results of the Krustkal-Wallis H test indicated at least one group experienced significantly different levels of enjoyment over the course of the study [$\chi^2(3) = 64.83$, $p < .001$, Cohen's $f = 0.23$], with responses (mean $\pm$ SD) on a 7-point Likert scale averaging 6.36 $\pm$ 0.84, 6.14 $\pm$ 1.13, 5.98 $\pm$ 1.31, and 6.62 $\pm$ 0.83, for the RiR, %1RM, RM, and RPE groups, respectively. To determine which groups in particular exhibited significantly different levels of enjoyment, multiple Mann-Whitney U tests were run using an adjusted alpha level of .0083 ($p = .05/6$). Results of the pairwise analysis indicated subjects in the RPE group experienced significantly higher levels of enjoyment than subjects in all other groups [RiR: mean difference = 0.26, U = 44009.00, $p \leq .001$; %1RM: mean difference = 0.48, U = 36238.00, $p \leq .001$; RM: mean difference = 0.64, U = 44794.50, $p \leq .001$]. No significant pairwise differences in enjoyment were found between any other groups (RiR, %1RM, RM). Comprehensive results of this analysis are presented on Table 12.

Perceived Tolerance

Evaluation of between-group differences in perceived tolerance was conducted under a non-parametric model due to non-normality in the survey data (skewness = -2.0; kurtosis = 5.6). Results of the Krustkal-Wallis H test indicated at least one group experienced significantly different levels of perceived tolerance over the course of the study [$\chi^2(3) = 109.78$, $p < .001$, Cohen's $f = 0.27$], with responses (mean $\pm$ SD) on a 7 point Likert scale averaging 6.38 $\pm$ 0.78, 6.13 $\pm$ 1.11, 6.10 $\pm$ 1.12, and 6.74 $\pm$ 0.63, for the RiR, %1RM, RM, and RPE groups, respectively. To determine which groups exhibited significantly different levels of perceived tolerance, multiple Mann-Whitney U tests were run using an adjusted alpha level of .0083 (p = .05/6). Results of the pairwise analysis indicated subjects in the RPE group found the exercise significantly more tolerable than subjects in all other groups [RiR: mean difference = 0.36, U = 39365.50, $p \leq .001$; %1RM: mean difference = 0.61, U = 30285.00, $p \leq .001$; RM: mean difference = 0.64, U = 39376.50, $p \leq .001$]. No other significant differences in perceived tolerance were found between any other combination of groups (RiR, %1RM, RM). Comprehensive results of this analysis are presented on Table 13.

Adherence

From the 82 people who successfully completed the 2-week familiarization and pre-testing phase, 71 ultimately completed the study. 5 individuals withdrew from the study for reasons unrelated to the study, and 6 withdrew for reasons possibly related to the study. Detailed information about dropouts including timing, rationale, relation to the study, and post-testing status can be found in Figure 1. Despite indicating on the pre-participation screening checklist that they planned to reside in the local area for the duration of the study, 13 subjects informed us after the start of training that they had made travel plans and would be leaving the study temporarily. This was not ideal; however, the decision was made to keep these subjects in the study and extend their participation by the length of time they were absent in order to ensure they completed all 22 scheduled training sessions. Upon completion of the study subjects were classified as either total compliers (completed all 22 training sessions within the allotted 9 week period; n=55), late compliers (completed all 22 training sessions in > 9 weeks; n=12), or partial compliers (did not complete all training sessions; n = 5). Partial compliers consisted of two dropouts who returned for post-testing, one individual who left the local area with three training sessions remaining due to seasonal travel plans, and two individuals who could not complete the final three training sessions because they came down with an extended illnesses near the end of the study that precluded them from completing all training sessions before the study completion date. Details about these individuals are presented in Figure 1.

To determine whether late and partial compliers' non-continuous participation had a skewing effect on the overall results of the study, multiple ANCOVA, controlling for pre-test values, were run to see if any significant differences existed between total, late, and partial compliers with respect to post-test strength and functional measures. No differences were identified and no further distinction was made in the analysis based on compliance.

CHAPTER 4: DISCUSSION

This study demonstrates that all progression methods tested were equally effective at improving muscular strength and functional capacity. The similarity in strength and selected functional measures among the three training methods was expected given results previously reported in the literature. A novel finding is that the RPE method was significantly more tolerable and enjoyable than the RM, RiR, or %1RM methods. Although higher tolerance and enjoyment of using the RPE method is supported theoretically, to our knowledge, this is the first study to quantify these differences.

Given our results, the RPE method appears to be the optimal load progression technique for strength training of older adults; because older individuals are likely to find RT significantly more tolerable and enjoyable, yet no less efficacious, than if the RM, %1RM, or RiR methods are utilized. Individuals who find exercise more tolerable and enjoyable, are significantly more likely to continue on a long term basis.[6] Additionally, while differences in adverse events did not reach the level of statistical significance, the fact that subjects in the RPE group (2.3$\pm$3.6) averaged less than half the number of WAEs than subjects in the, RiR (5.8$\pm$8.7) and RM groups (5.7 $\pm$7.7), should be considered. As noted by Shaw, McCully, and Posner[43], injury resulting from physical conditioning is an important deterrent in continuing an exercise regimen.

Repetition Maximum (RM) Method

The underlying principle of the repetition maximum (RM) method is that training loads are increased when an individual is able to complete a target number of repetitions with a given load without assistance or excessive rest between repetitions.[3,5,19,75] Support for use of the RM method in older adults is supported by its regular use in relevant research[3,22,23] and the fact that it is advocated by the American College of Sports Medicine in their position stands on progression models for strength training in healthy[16]vand healthy older adults.[6] The most significant criticism of the RM method is that it involves training to the point of muscular failure[25-27], which can be an uncomfortable and discouraging experience, especially for novices. The method often involves higher perceived effort and post-exercise discomfort in untrained individuals[3,5,29], which may in turn discourage continued participation in RT.

Subjects in the RM group experienced significant improvements in upper and lower body maximum strength comparable to those previously reported[5,22,23], as well as improvements in average training load, gallon jug transfer test, and 30 second sit-to-stand. Although some researchers have theorized that the RM method should generate the greatest maximum strength improvement of the four methods investigated in this study[14], our results do not support this supposition. Of the four methods investigated, the subjects in the RM method reported the lowest average enjoyment, lowest perceived tolerance, and second highest rate of adverse events. One individual in this group sustained a severe back strain while performing the seated row in week 6 after having had the training load in this exercise raised every second workout without interruption. Given these results, we conclude that the RM method is not optimal for improving strength in older adults.

Percent (%1RM) Method

The percent one-repetition maximum (%1RM) method involves prescribing training loads based on a percentage of the exerciser's maximum strength level in a given exercise, and is commonly utilized in athletes' training for sport performance.[30] This means an individual with a 1RM of 100kg would use a working load of 70kg. The

%1RM method has particular utility because it allows targeted RT programs to be developed for specific types of muscular adaptation. To induce muscular hypertrophy, for example, training loads approximating 60-70% of the 1RM have been shown to be ideal, whereas training loads approximating 80-90% of the 1RM have been shown to be most effective for inducing improvements in muscular strength. [30]

The main reason why the %1RM method has been theorized as optimal for older adults is that it may induce the largest increases in maximal muscular strength.[29] In a recent meta-analysis[29] looking at the effects of multimodal RT on frail older adults' maximal strength and functional capacity, researchers found substantially greater increases in maximal strength (standardized mean difference = 1.81 vs. 0.30) in studies using the %RM method compared to the ratings of perceived exertion (RPE) method. The authors hypothesized that the reason the %1RM was so much more effective than the RPE method was that untrained older adults may have lower perceptions of intensity, which could lead to an under-estimation of the appropriate workload and potentially attenuate the magnitude of their realized strength gains. One concern when using the %RM method in older adults is that it is time consuming as dedicated sessions must be conducted to determine the 1RM for each exercise. Additionally, it is difficult to adjust in real time to improvements in strength, since adjustments to the working load cannot be made without conducting another 1RM testing session. For untrained individuals, the need to frequently re-establish 1RMs may be particularly laborious given that this population is known to experience rapid strength gains in the early stages of a new RT program.[2,76] Additionally, maximal strength testing is often an overwhelming experience and requires great focus and intensity of effort to provide an accurate result.[14,36,42] This means that individuals new to RT may be discouraged from further participation if they find the initial testing session uncomfortable or too intense.[3,42]

Subjects in this group also experienced significant improvements in upper and lower body maximum strength that were similar to those reported in other studies employing this progression technique.[32,33,35] They also produced significant improvements in average training load, gallon jug transfer test, and timed up and go. As with the RM method, the theory that the %1RM method would lead to greater strength gains than the RPE method[29] was not supported by our data. Subjects in the %1RM group experienced the second lowest levels of perceived tolerance and enjoyment. This group had the highest number of dropouts at five, and the highest number who discontinued participation for reasons possibly related to the study at four. We conclude that the %1RM method is not the best choice for strength training in older adults.

Repetition in Reserve (RM) Method

The repetitions in reserve method (RiR) is the most recent of the four progression models examined in this study, and therefore has the least support in the literature. Despite this limitation, a sound rationale exists for its use in older adults. The RiR method is identical to the RM method with the key distinction that instead of performing each set until failure, subjects stop when they perceive they are only capable of performing one more repetition, that is they have one more repetition 'left in reserve'.[24,54,58] Progressions are structured similarly to those used in the RM model: training loads are increased when subjects report having one or more repetitions left 'in reserve' at the end of each set. The primary advantage of the RiR method is it eliminates the need for participants to train to the point of temporary muscular failure, while ensuring they maintain an intensity that will provide a strong stimulus for strength adaptations. As with the RPE approach, the RiR method may be ideal for older adults as it can account for variations in factors such as sleep [59], nutrition [60], stress [61], and recovery [37,38] that may affect daily exercise performance.

A significant limitation to the use of the RiR method in older adults is the low number of available studies [24,58] including a complete absence of those involving older adults. Also, similar to the RPE method, the utility of the RiR may be limited by the time required for novice exercisers to gain familiarity with the scale, so they can determine when they truly have only a single repetition in reserve. [24,58]

The RiR method was of considerable interest because it was supported by the smallest volume of literature, but appeared to offer a perfect compromise between the RM and RPE methods.[3] Instructing subjects to stop when they had one repetition in reserve eliminated the possibility of training to true muscular failure, yet it offered weight progressions predominantly based on performance, rather than perceived effort alone, as was the case in the RPE method. Subjects in this group experienced significant improvement in strength that were comparable to those seen in two previous studies [24,58] and improvements in timed up-and-go and 30 second sit-to-stand performance over the course of the study. This method was found to be the second most enjoyable and tolerable method investigated in this study and may be preferable to the RM and %1RM methods. While this group had the second-highest number of dropouts at four, only one was for a reasons related to the study.

RPE Method

The essence of the rating of perceived exertion (RPE) method is that training loads are increased when the exerciser perceives a given load to fall below a predetermined level of difficulty. [47] The method has been extensively utilized in research related to RT in older adults [48,49,51,52] and of all the methods considered, the RPE method gives exercisers the most control over their working loads. The primary benefit of the RPE method is it ensures all subjects complete each set without reaching the point of muscular failure, thereby reducing the risk of injury and/or muscle soreness.[2] The RPE method may be ideal for use with older adults as it allows for adjustments to be made to an exerciser's working load on a session-by-session basis based on their subjective feelings such as residual soreness or fatigue, and overall may be perceived as less intimidating. Additionally, the rate at which training loads increase from session to session is typically lowest with the RPE method, which may be desirable for novice individuals or those concerned about their program increasing in intensity too quickly.[2,48]

One of the limitations of the RPE method is it requires exercisers to be familiar with the scale that is being used to measure perceived exertion and with the physical sensation of giving maximal effort in a RT exercise.[54] The RPE method may also be inappropriate for use with trained individuals, as it has been shown that some individuals do not report maximal RPE values even when performing maximal repetitions to failure.[55-57] Lastly, the use of the RPE method in older adults may be limited as it requires significant documentation and program analysis: administrators (or exercisers themselves) must ask for and record subjects' RPE after each set and maintain a log over multiple sessions to determine when it is appropriate to increase the load for a given exercise.

Because the RPE method relies on subjective perceptions of difficulty, rather than an objective performance criterion as employed in the RM and RiR methods, we theorized that individuals in this group might not experience the same level of strength improvement as subjects in the RM, RiR, or %1RM methods. Contrary to this hypothesis, individuals in this group demonstrated strength gains similar to other treatment groups. These improvements, coupled with the highest reported levels of enjoyment and perceived tolerance and no dropouts, suggest that the RPE method is the optimal RT progression model to use with older adults.

Study Limitations

A limitation to this study is the relatively modest number of subjects in each group. The statistical power obtained for between-group differences in CP and LP 1RM was 0.10 and 0.11, respectively, meaning that with a larger sample size the small effect sizes observed between groups for improvements in CP and LP (0.11, 0.11) may have reached statistical significance. Although we report no significant difference between the groups on any strength or functional performance outcome, it should be recognized that large variances and confidence intervals were observed, which may have prevented detection of a true between-group effect. Therefore, we suggest repeating the study with a larger or more-homogeneous sample. An additional limitation to the study, which is also a direction for future research, is the impact of personality type and previous RT experience on the optimal progression model. Some individuals in the RPE group, for example, were unaccustomed to RT and determined that if they gave an RPE score ≤ 8, their loads would go up. These individuals gave the impression of not wanting their training loads to change, and consistently gave RPE scores of between 8 and 10, and subsequently their training loads did not increase for the duration of the study. The possibility exists that for some people, a purely subjective method, such as the RPE method, is not viable as it allows them to remain at a given load indefinitely, potentially undermining their long-term strength gains. On the other hand, some individuals in the RM group had a determined mentality that they were going to complete the target number of repetitions regardless of the level of exertion. In fact, one such individual had to withdraw from the study because he sustained a serious muscle strain that caused him to withdraw from the study. It is possible for individuals predisposed to give a maximum effort in each session that a method such as the RPE or RiR could reduce the potential for injury.

Conclusions

In this sample of 82 healthy community-dwelling older adults it was determined that the RPE method was the best way to progress loads in older adults. Higher-intensity methods, such as the RM and RiR, thought to lead to greater strength improvement due to higher intensities were not found to lead to greater strength improvement than the RPE method and were significantly less tolerable and enjoyable. In other words, the increased effort associated with the RM, RiR, or %1RM methods, does not appear to lead to improved outcomes. As such, the rationale for their use in RT for older adults may be debatable.

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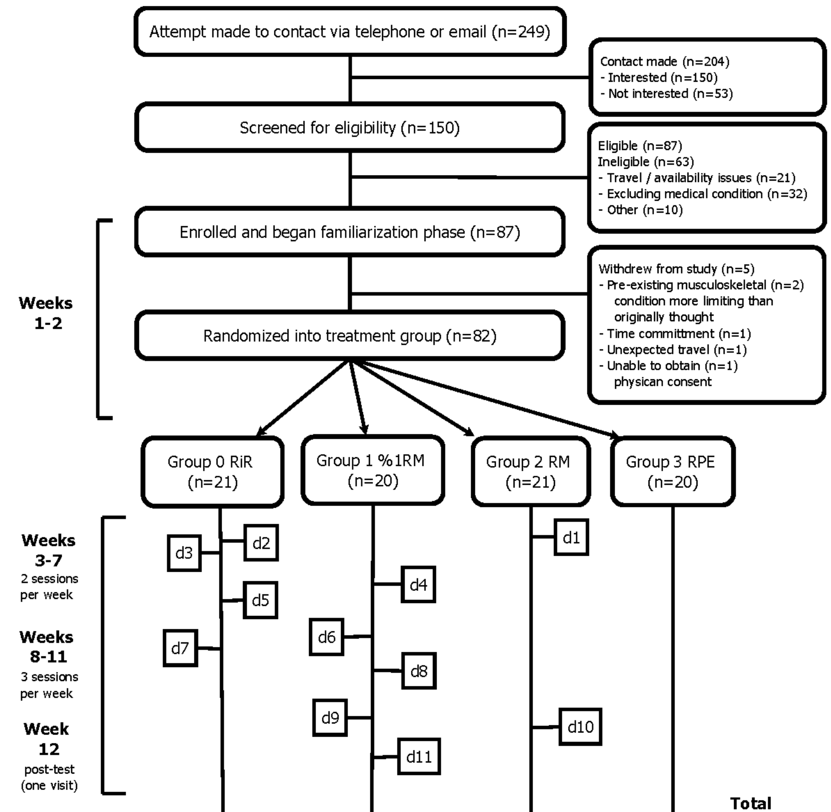
FIGURES

Figure 1. Overview of recruitment and subject flow though the study including dropouts (CONSORT)



	Group 0 RiR	Group 1 %1RM	Group 2 RM	Group 3 RPE	Total
Post-testing (n=	17	16	20	20	73
- Total compliers	14	14	13	14	55
- Late compliers	3	0	4	6	13
- Partial compliers	0	2	3	0	5
Dropouts	4	5	2	0	11
- Definitely unrelated	3	1	1	0	5
- Possibly related, did post-test	0	1	1	0	2
- Possibly related, did not post test	1	3	0	0	4

DROPOUTS: d1: after randomization, definitely unrelated, pituitatary cancer diagnosis; d2: after randomization, definitely unrelated, complications due to double masectomy; d3: after randomization, definitely related, recovery complications from elective surgery; d4: week 3, definitely unrelated, extended holiday travel; d5: week 3, possibly related, aggravated previously-dormant sciatica, no post test; d6: week 3 , possibly related, did not return after an extended bout with, did post test; d7: week 4, definitely unrelated, had to leave the state for an extended period to care for ailing relative; d8: week 4, possibly related; time committment became untenable, nopost test; d9: week 5, possibly related, travel time to the lab became untenable, did not post test; d10: week 6, possibly related,left due to back strain caused by participation in the study, did post test; d11: week 6, possibly related, worried participation in study was causing systemic inflammation, did not post test.

Figure 2. Familiarization and baseline phase overview

Screening Checklist
- in person or over telephone
- assess for eligibility

Excluded if:
- <60 or > 90 years of age
- regularly weight train (> 1 x week)
- are paricipating in another exercise study
- cannot commit to study duration
- don't meet all inclusion criteria
- meet one or more exclusion criteria

Week 1 Day 1
- Intake paperwork (informed consent, health history form, Mini-Mental Exam)
- Anthropometric measures (height, weight)
- Usual walking speed
- Familiarization on machines (2 sets x 10 reps, work up to RPE of 6)

Week 1 Day 2
- Timed Up-and-Go familiarization
- Gallon jug transfer test familiarization
- Familiarization on machines (2 sets x 10 reps, work up to RPE of 7)

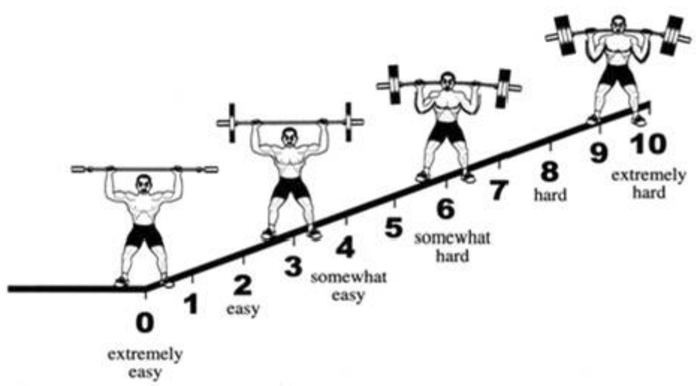
Week 1 Day 3
- Chest and leg press 1RM familiarization
- Familiarization on machines (3 sets x 8 reps, work up to RPE of 8)

Week 2 Day 1
- Usual walking speed
- Timed Up-and-Go
- Gallon jug transfer test
- Physical function video questionnaire
- Familiarization on machines (3 sets x 8 reps, work up to RPE of 8)

Week 2 Day 2
- Chest and leg press familiarization
- Familiarization on machines (3 sets x 8 reps, work up to RPE of 8)

Figure 3. OMNI RES Rating of Perceived Exertion

Figure 3. Rating of perceived exertion scale.



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TABLES

Table 1. Baseline characteristics by group by and overall cohort.

	RiR (*n* = 21)	%1RM (*n* = 20)	RM (*n* = 21)	RPE (*n* = 20)	Total Cohort (*n* = 82)
Age (y)	72.3 (5.7)	69.6 (7.4)	72.3 (6.6)	73.1 (4.7)	71.8 (6.2)
Male Subjects (n)	8	7	8	7	30
Female Subjects (n)	13	13	13	13	52
Proportion Female	0.62	0.65	0.62	0.65	0.63
BMI	27.3 (5.6)	27.0 (6.4)	28.0 (4.4)	27.9 (4.3)	27.5 (5.2)
TES	1.3 (1.1)	1.6 (1.4)	1.5 (1.3)	1.7 (1.6)	1.5 (1.3)

All values expressed as mean (SD); *significantly different from at least one other group ($p < 0.05$); RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; BMI = body mass index; TES = training experience score (range: 0-5).

Table 2. Pre- and post-test means for strength and functional measures by group and by overall cohort.

	RiR (n = 21)		%1RM (n = 20)		RM (n = 21)		RPE (n = 20)		Total Cohort (n = 82)	
	Baseline (n = 21)	Post-Test (n = 17)	Baseline (n = 20)	Post-Test (n = 16)	Baseline (n = 21)	Post-Test (n = 20)	Baseline (n = 20)	Post-Test (n = 20)	Baseline (n = 82)	Post-Test (n = 73)
LP 1RM (kg)	154.8 (57)	181.2 (65)*	145.1 (42)*	167.6 (57)*	148.1 (49)	173.6 (49)*	147.7 (48)	170.7 (62)*	149 (49)	173.3 (57)*
CP 1RM (kg)	33.0 (16.2)	39.1 (18.3)*	29.7 (12.1)	34.8 (14.6)*	30.2 (15.2)	34.0 (15.7)*	30.2 (14.0)	33.9 (15.8)*	30.8 (14.3)	35.3 (16.0)*
ATL (kg)	42.5 (12.9)	64.2 (21.0)*	46.3 (13.7)	53.4 (17.4)*	40.0 (14.6)	62.6 (22.2)*	39.7 (14.5)	50.7 (18.3)*	42.1 (13.9)	57.5 (20.2)*
Usual WS (s)	3.8 (0.7)	3.8 (0.62)	3.9 (0.6)	3.7 (0.5)	3.8 (0.5)	3.7 (0.6)	3.8 (0.7)	3.7 (0.9)	3.8 (0.6)	3.8 (0.7)
Maximum WS (s)	2.8 (0.5)	2.7 (0.59)	2.5 (0.4)	2.5 (0.3)	2.4 (0.4)	2.4 (0.4)	2.6 (0.4)	2.4 (0.5)*	2.6 (0.5)	2.5 (0.4)*
TUG (s)	6.2 (1.3)	6.0 (1.4)*	5.9 (1.1)	5.4 (0.8)*	6.1 (1.1)	5.8 (1.2)	6.1 (1.3)	5.6 (1.5)*	6.1 (1.2)	5.7 (1.3)*
GJ (s)	9.1 (1.8)	8.7 (1.8)	8.4 (1.2)	7.8 (0.8)*	8.6 (1.2)	8.1 (1.4)*	9.0 (3.2)	8.2 (3.2)*	8.8 (2.0)	8.2 (2.0)*
STS (n)	14.0 (2.5)	15.2 (3.5)*	15.2 (3.5)	16.7 (3.4)	14.3 (2.6)	15.6 (2.4)*	15.2 (3.7)	15.6 (3.5)	14.7 (3.1)	15.7 (3.2)*

All values expressed as mean (SD); *significantly different from pre-test values ($p < 0.05$); RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; BMI = body mass index; TES = training experience score (range: 0-5); LP = leg press; CP = chest press; ATL = average training load; WS = walking speed; TUG = timed up and go; GJ = gallon jug shelf transfer test; STS = 30 second sit to stand test; kg = kilogram; s = second

Table 3. Comprehensive results of the ANCOVA analysis of between-group differences in post-test LP 1RM.

	df (SS)	F Statistic	Significance (*p*)*	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (1.0×10^5)	148.9	< .001	.896	1	.433
Significance of Baseline Values as a Covariate	1 (1.0×10^5)	590.6	< .001	.895	1	
Group Main Effect	3 (1.6×10^3)	.312	.817	.013	.107	

Pairwise Comparisons

	Mean Difference (kg; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR - %1RM	-.26 (14.34)	1.00	-39.22	38.69
RiR - RM	-11.49 (13.79)	1.00	-48.95	25.96
RiR - RPE	-4.20 (13.78)	1.00	-41.65	33.25
%1RM - RM	-11.23 (13.74)	1.00	-48.56	26.10
%1RM - RPE	-3.94 (13.74)	1.00	-28.49	43.07
RM - RPE	7.29 (13.17)	1.00	-28.49	43.07

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; LP = leg press; kg = kilogram

Table 4. Comprehensive results of the ANCOVA analysis of between-group differences in post-test CP 1RM.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (8.5 x 10^3)	322.62	< .001	.949	1	.312
Significance of Baseline Values as a Covariate	1 (8.3 x 10^3)	1266.86	< .001	.948	1	
Group Main Effect	3 (58.24)	.293	.830	0.013	.104	

Pairwise Comparisons

	Mean Difference (kg; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	-.93 (2.80)	1.00	-8.55	6.69
RiR vs. RM	-.208 (2.70)	1.00	-7.55	7.13
RiR vs. RPE	1.48 (2.70)	1.00	-5.85	8.81
%1RM vs. RM	.722 (2.68)	1.00	-6.57	8.01
%1RM vs. RPE	2.41 (2.68)	1.00	-4.88	9.70
RM vs. RPE	1.69 (2.57)	1.00	-5.30	8.68

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; CP = chest press; kg = kilogram

Table 5. Comprehensive results of the ANCOVA analysis of between-group differences in post-test ATL.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (1.3×10^5)	172.80	< .001	.912	1	.206
Significance of Baseline Values as a Covariate	1 (1.2×10^5)	628.13	< .001	.904	1	
Group Main Effect	3 (1.6×10^4)	29.33	< .001	.568	1	

Pairwise Comparisons

	Mean Difference (kg; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	30.06 (4.75)	< .001	17.13	42.99
RiR vs. RM	-9.18 (4.65)	.316	-21.83	3.47
RiR vs. RPE	17.50 (4.60)	.002	5.00	30.00
%1RM vs. RM	-39.25 (4.61)	< .001	-51.79	-26.70
%1RM vs. RPE	-12.57 (4.56)	.045	-24.96	-.17
RM vs. RPE	26.68 (4.37)	< .001	14.80	38.55

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; ATL = average training load; kg = kilogram

Table 6. Comprehensive results of the ANCOVA analysis of between-group differences in post-test usual WS.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (18.17)	19.09	< .001	.529	1	.754
Significance of Baseline Values as a Covariate	1 (18.00)	75.65	< .001	.527	1	
Group Main Effect	3 (.10)	.135	.939	.006	.073	

	Pairwise Comparisons			
	Mean Difference (s; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	.05 (.17)	1.00	-.41	.51
RiR vs. RM	-.05 (.16)	1.00	-.49	.39
RiR vs. RPE	.02 (.16)	1.00	-.42	.46
%1RM vs. RM	-.10 (.16)	1.00	-.55	.35
%1RM vs. RPE	-.03 (.16)	1.00	-.48	.41
RM vs. RPE	.07 (.15)	1.00	-.35	.49

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; WS = walking speed; s = seconds

Table 7. Comprehensive results of the ANCOVA analysis of between-group differences in post-test maximum WS.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (1.3×10^5)	35.88	< .001	.682	1	.321
Significance of Baseline Values as a Covariate	1 (1.2×10^5)	131.56	< .001	.663	1	
Group Main Effect	3 (1.6×10^4)	.456	.714	.020	.137	

	Pairwise Comparisons			
	Mean Difference (s; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	0 (.09)	1.00	-.25	.25
RiR vs. RM	-.06 (.09)	1.00	-.30	.19
RiR vs. RPE	.04 (.09)	1.00	-.20	.28
%1RM vs. RM	-.06 (.09)	1.00	-.29	.18
%1RM vs. RPE	.04 (.09)	1.00	-.20	.28
RM vs. RPE	.10 (.08)	1.00	-.13	.32

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; WS = walking speed; s = seconds

Table 8. Comprehensive results of the ANCOVA analysis of between-group differences in post-test TUG.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (81.5)	35.60	< .001	.680	1	.838
Significance of Baseline Values as a Covariate	1 (77.4)	135.22	< .001	.669	1	
Group Main Effect	1 (1.56)	.91	.441	.039	.239	

	Pairwise Comparisons			
	Mean Difference (s; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	.30 (.27)	1.00	-.42	1.02
RiR vs. RM	-.12 (.25)	1.00	-.80	.58
RiR vs. RPE	.09 (.25)	1.00	-.59	.77
%1RM vs. RM	-.41 (.26)	.675	-1.11	.28
%1RM vs. RPE	-.21 (.25)	1.00	-.90	.48
RM vs. RPE	.21 (.24)	1.00	-.87	.45

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; TUG = timed up and go; s = seconds

Table 9. Comprehensive results of the ANCOVA analysis of between-group differences in post-test GJ.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (233.4)	64.97	< .001	.793	1	.427
Significance of Baseline Values as a Covariate	1 (226.9)	252.61	< .001	.788	1	
Group Main Effect	3 (2.28)	.846	.473	.036	.225	

	Pairwise Comparisons			
	Mean Difference (s; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	.49 (.31)	.879	-.41	1.39
RiR vs. RM	.22 (.31)	1.00	-.63	1.08
RiR vs. RPE	.38 (.31)	1.00	-.47	1.23
%1RM vs. RM	-.26 (.32)	1.00	-1.13	.60
%1RM vs. RPE	-.10 (.32)	1.00	-.97	.76
RM vs. RPE	.16 (.31)	1.00	-.66	1.13

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; GJ = gallon jug transfer test; s = seconds

Table 10. Comprehensive results of the ANCOVA analysis of between-group differences in post-test STS.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	4 (422.3)	23.56	< .001	.592	1	.651
Significance of Baseline Values as a Covariate	1 (401.4)	89.65	< .001	.580	1	
Group Main Effect	3 (9.82)	.731	.537	.033	.198	

Pairwise Comparisons

	Mean Difference (n; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	-.58 (.76)	1.00	-2.64	1.48
RiR vs. RM	-.22 (.72)	1.00	-2.17	1.72
RiR vs. RPE	.45 (.70)	1.00	-1.47	2.36
%1RM vs. RM	.36 (.74)	1.00	-1.67	2.38
%1RM vs. RPE	1.03 (.72)	.950	-.94	3.00
RM vs. RPE	.67 (.69)	1.00	-1.21	2.55

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve; %1RM = percent 1RM; RM = repetition maximum; RPE = ratings of perceived exertion; STS = 30 second sit to stand test; n = number of repetitions completed

Table 11. Comprehensive results of the ANOVA analysis of between-group differences in weighted adverse events.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	3 (209.5)	1.75	.164	.067	.439	0.012

	Pairwise Comparisons			
	Mean Difference (n; ± SE)	Significance (*p*)	95% CI Lower Limit	95% CI Upper Limit
RiR vs. %1RM	3.04 (2.01)	.883	-2.59	8.68
RiR vs. RM	.08 (2.05)	1.00	-5.48	5.65
RiR vs. RPE	3.58 (2.05)	.510	-1.98	9.15
%1RM vs. RM	-2.96 (2.02)	.886	-8.45	2.53
%1RM vs. RPE	.54 (2.02)	1.00	-4.95	6.03
RM vs. RPE	3.50 (2.00)	.503	-1.92	8.92

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group; n = number of weighted adverse events

Table 12. Comprehensive results of the non-parametric analysis of between-group differences in enjoyment.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	3 (80.4)	24.26	< .001	.052	1	< .001

	Pairwise Comparisons		
	Mean Difference ($\pm$ SE)	Mann-Whitney U	Asymptotic Significance (*p*)
RiR vs. %1RM	.22 (.08)	43818.50	.064
RiR vs. RM	.38 (.08)	53121.50	.009
RiR vs. RPE	-.26 (.08)	44009.00	< .001
%1RM vs. RM	.16 (.08)	50447.00	.354
%1RM vs. RPE	-.48 (.08)	36238.00	<.001
RM vs. RPE	-.64 (.08)	44794.50	<.001

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group

Table 13. Comprehensive results of the non-parametric analysis of between-group differences in perceived tolerance.

	df (SS)	F Statistic	Significance (*p*)	Effect Size (Partial η^2)	Observed Power	Levene's Test for Equality of Error Variances (*p*)
Overall Model	3 (87.2)	33.5	< .001	.063	1	< .001

	Pairwise Comparisons		
	Mean Difference (± SE)	Mann-Whitney U	Asymptotic Significance (*p*)
RiR vs. %1RM	.25 (.08)	41753.50	.016
RiR vs. RM	.28 (.07)	53135.00	.009
RiR vs. RPE	-.36 (.07)	39365.50	< .001
%1RM vs. RM	.02 (.07)	51148.00	.907
%1RM vs. RPE	-.61 (.08)	30285.00	< .001
RM vs. RPE	-.64 (.07)	39376.50	< .001

SE = standard error; SS = Type III sum of squares; df = degrees of freedom; RiR = repetitions in reserve group; %1RM = percent 1RM group; RM = repetition maximum group; RPE = ratings of perceived exertion group