Optimal Approach to Load Progressions during Strength Training in Older Adults

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ABSTRACT

BUSKARD, A. N. L., K. A. JACOBS, M. M. ELTOUKHY, K. L. STRAND, L. VILLANUEVA, P. P. DESAI, and J. F. SIGNORILE. Optimal Approach to Load Progressions during Strength Training in Older Adults. *Med. Sci. Sports Exerc.*, Vol. 51, No. 11, pp. 2224–2233, 2019. Progressive resistance training (RT) is one of the most effective interventions for reducing age-related deficits in muscle mass and functional capacity. **Purpose:** To compare four approaches to load progressions in RT for older adults to determine if an optimal method exists. **Methods:** Eighty-two healthy community-dwelling older adults (71.8 ± 6.2 yr) performed 11 wk of structured RT (2.5 d·wk^{-1}) in treatment groups differing only by the method used to increase training loads. These included percent one repetition maximum (%1RM): standardized loads based on a percentage of the one repetition maximum (1RM); rating of perceived exertion (RPE): loads increased when perceived difficulty falls below 8/10 on the OMNI-Resistance Exercise Scale perceived exertion scale; repetition maximum (RM): loads increased when a target number of repetitions can be completed with a given load; repetitions in reserve (RiR): identical to RM except subjects must always maintain ≥1 "repetition in reserve," thus avoiding the possibility of training to temporary muscular failure. **Results:** Multiple analyses of covariance indicated no significant between-group differences on any strength (chest press 1RM; leg press 1RM) or functional performance outcome (usual walking speed, maximum walking speed, 8-ft timed up-and-go, gallon jug transfer test, 30 s sit-to-stand). The RPE group found the exercise to be significantly more tolerable and enjoyable than subjects in the RiR, RM, and %1RM groups. **Conclusion:** Given the RM, RPE, %1RM, and RiR methods appear equally effective at improving muscular strength and functional performance in an older population, we conclude that the RPE method is optimal 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. **Key Words:** INTENT-TO-TREAT, STRENGTH TRAINING, OLDER ADULTS, REPETITIONS IN RESERVE

Progression and enjoyment are two critical factors to consider when designing a resistance training (RT) program for an older adult. Programs that progress too slowly, either in intensity or volume, are unlikely to maximize participants' potential for adaptation, whereas programs that progress too quickly may lead to overuse injuries and overtraining syndrome (1–3). Accordingly, the ideal progression model to use with an older adult is one in which there is a smooth increase in loading intensity that optimizes strength gains while preserving interest levels and enjoyment. The need for appropriate progressions in strength training by older adults is well documented; however, there is no consensus among researchers concerning the best strategy (3,4).

To date, three dominant approaches have been used by researchers: perceived exertion, target repetitions, and percentage of maximum. Clear and compelling evidence exists to support each of these methods in older adults; however, there are also rationales that propose why each should be avoided. The repetitions-to-failure method, for example, has been suggested as optimal by some researchers (5) because it may provide the greatest physiological stress on the exerciser (a potent stimulus for muscular adaptation), whereas other researchers have suggested that training to the point of temporary muscular failure is unnecessary and likely to cause delayed onset muscle soreness and discomfort (5–7). Additionally, if unfamiliar loads or exercises are provided this may further exacerbate the risk of delayed onset muscle soreness. Further, it has

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been suggested that program variables relating to variations in loading intensity may not have a significant effect in the early stages of RT participation for older persons (7,8), meaning exercise interventions that are perceived to be more tolerable and enjoyable may be preferable, even if they lead to marginally lower strength increases.

Contrary to the goal of RT for sport, which is to maximize competition-specific strength, a more conservative approach is warranted when evaluating the merit of a RT protocol for older adults (9–11). Older adults' perceptions of their experience in an exercise program are among the major determinants of whether they will continue participation (11). Unlike RT programs designed to improve sport performance, the RT method that produces the greatest absolute increase in muscular strength or power may not be the most effective for older individuals if it negatively influences perceived enjoyment and tolerance (10). As stated by Van Roie et al. (10), if only a limited number of older adults are motivated to engage in an RT intervention, its overall benefit to public health should be questioned.

If the overall goal of RT for older adults is long-term participation, features that are likely to have a negative impact on adherence are critical to consider when determining which intervention to advocate. Previous research has demonstrated that older adults typically prefer less-challenging exercise modalities (12), are less likely to report exercise as feeling "good" (9), are more likely to be dissuaded from exercise due to fear of injury (9,10,13), feel less in-control of their exercise behavior (12), and are more likely to continue an exercise program if they find it to be enjoyable (9,14). Additionally, it has been suggested that lower exercise intensities may lead to higher adherence rates in older adults, likely due to increased feelings of pleasure (10,15). These findings indicate that enjoyment and perceived tolerance are critical factors to consider when evaluating if an optimal progression method exists for RT in older adults.

The purpose of this investigation was to examine the efficacy, enjoyment, tolerance, adherence, and adverse event rate of three commonly used progression models for older adults to determine if an optimal method exists. A fourth model was also included that has yet to be studied in older adults, but has strong theoretical support. The methods were evaluated in terms of improvement in maximal strength, functional performance related to activities of daily living (ADL), average working load across all exercise machines, adherence rates, and perceptions of exercise enjoyment and tolerance.

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 posttesting, except those who withdrew for reasons unrelated to the study.

Subjects

Potential subjects were recruited using flyers posted in the local community, a database of previous research subjects, and word of mouth. One hundred 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 in Table 1.

Inclusion and exclusion criteria are detailed in Figure 2. Before 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 for their participation.

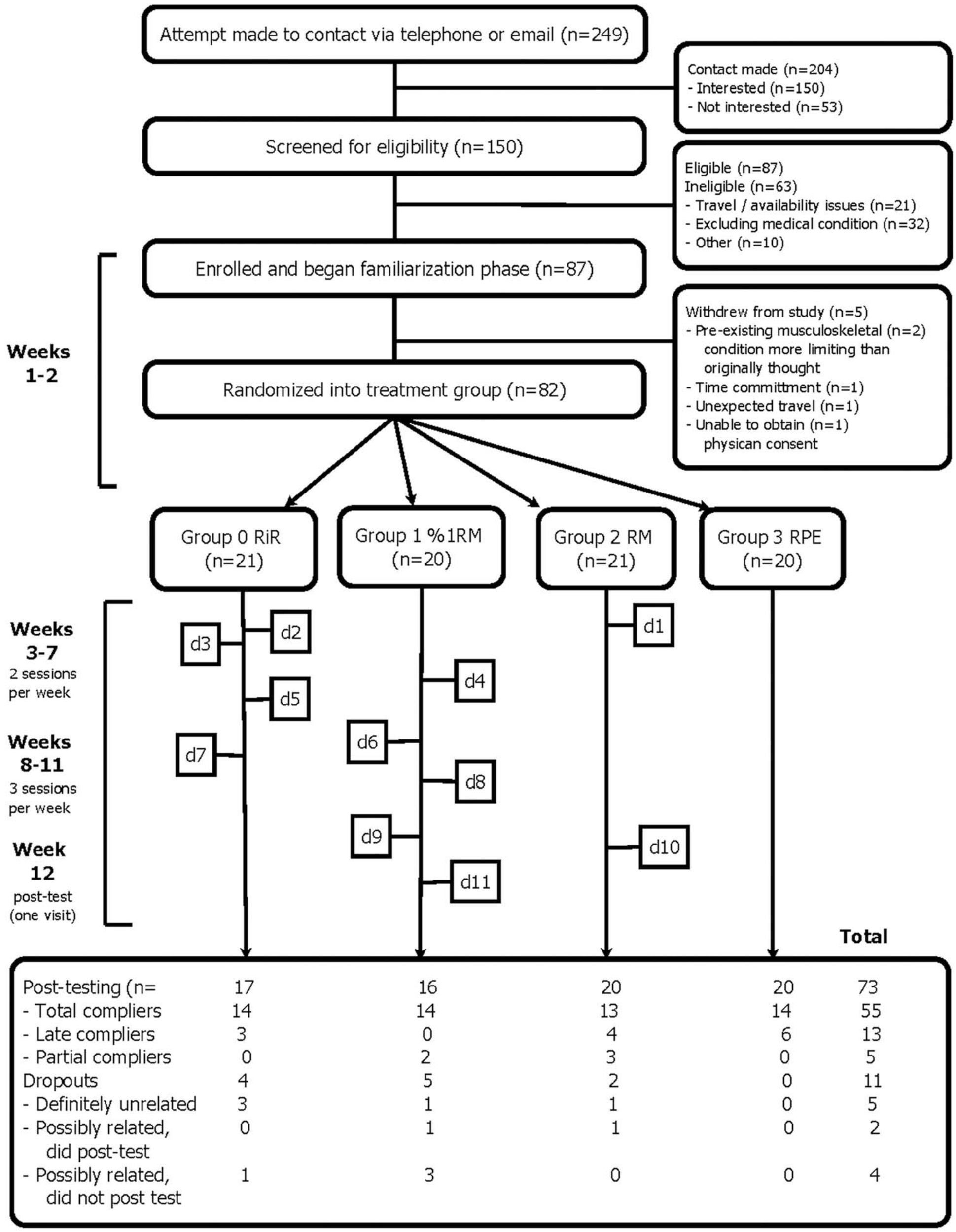
Procedures

Overview. Before group allocation, participants reported to the laboratory for five training sessions designed to familiarize them with the RT machines and to facilitate baseline data collection. A detailed overview of this phase is presented in Figure 2.

Subjects were considered enrolled in the study after successful completion of the fifth familiarization session and subsequently assigned to a treatment group using block randomization stratified by sex and lower-body one repetition maximum (1RM). Subjects were familiarized with the 1RM testing protocol on day 3 of the baseline testing phase in an attempt to maximize 1RM values. It has been widely reported that a single day of testing is insufficient to collect reliable 1RM values in older adults (8,16–18), likely due to factors related to a lack of familiarity with the assessment or ability to accurately perceive a maximum effort (8). All pretest and posttest data were collected by two blinded assessors with no other connection to the study.

Intervention. Eight pneumatic resistance exercise machines (Keiser A420; Kesier Sport, Fresno, CA) were used in this study (seated leg press [LP], seated chest press [CP], leg curl, hip adductor, seated row, lateral pulldown, biceps curl, triceps press-down). Participants completed two training sessions per week in weeks 1 to 5 of the intervention period and three training sessions per week in weeks 6 to 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 that participants in the percent 1RM (%1RM) group attended 1RM testing sessions after randomization, after week 5, and after posttesting to determine their initial, increased, and final working loads, respectively. An overview of the familiarization period can be found in Figure 2.

Although some researchers and clinicians have argued that submaximal protocols are preferential to 1RM testing in older



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 1—Overview of recruitment and subject flow through the study including dropouts (CONSORT).

adults, the body of available literature does not appear to support this contention. Proponents against the use of 1RM testing in this population typically cite a study by Pollock et al. (19); however, the article is widely understood to have limited validity in addressing this issue, due to limitations in their methodology and definition of an injury (20). As a consequence, the body of literature opposing 1RM testing in older adults is sparse and significantly outweighed by the body of literature supporting it. When reporting the injury rates associated with 1RM testing, Bellew (20) notes that across three of the most commonly cited studies on the topic (21–23) only a single injury was reported in 446 maximum strength tests for adults between the ages of 60 to 96 yr of age. The determination of the optimal progression methods for older adults depends heavily on the accuracy of strength measurements. Given the safety of 1RM testing and its status as the "gold standard" for assessing maximal strength, we determined 1RM was preferable to a submaximal approach involving multiple repetitions and a predictive equation.

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 (yr)	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, repetition in reserve; BMI, body mass index; TES, training experience score (range: 0–5).

Participants performed each exercise for three sets of seven repetitions. Rest periods were standardized to a minimum of 1 min by attaching digital countdown timers to each machine. Subjects were instructed to perform the concentric phase of each exercise as fast as possible to maximize neuromuscular adaptation (3,4) and to perform the eccentric (lowering) phase in a controlled (2 s) manner (2,3,8). A high-velocity concentric phase was chosen, because Hazell et al. (24), in their review of studies investigating the effect of RT on ADL in older adults, concluded that high-velocity RT appears more effective than traditional slow-velocity RT when targeting ADL performance. Rest times, intensity, frequency, and volume of training used in this study are all consistent with current recommendations for improving strength in older adults published by the American College of Sports Medicine (ACSM) in their position stand “Progression Models in Resistance Training for Healthy Adults” (2).

Repetition maximum group. Loads were increased (5% upper-body exercise, 10% lower-body exercise) when the participant was able to complete all sets and repetitions on

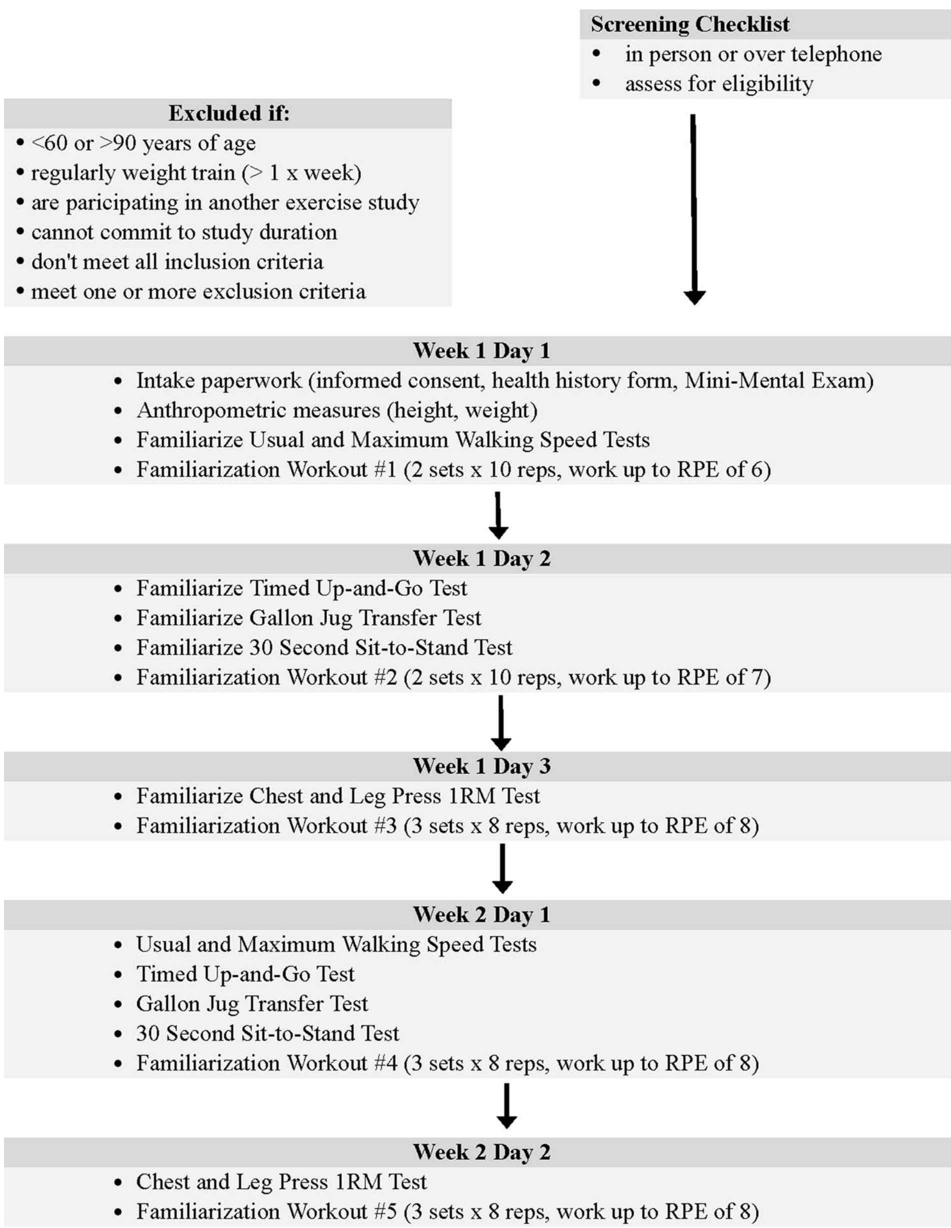


FIGURE 2—Overview of familiarization and baseline testing phase.

consecutive workouts without assistance, load reduction, or excessive between-set rest. These increments fall within the range recommended by the ACSM in their relevant position stand on progression models in RT (2) and have been used without adverse effects in similar studies with older adults (25–27). The starting load for each exercise was the load used in the final familiarization session.

%1RM group. The %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 training athletes for sport performance (28). Participants performed all sets and repetitions at 80% of their 1RM. Three 1RM testing sessions were conducted: after randomization (all machines excluding chest and LP), at the midway point of the study (all machines), and at the conclusion of posttesting in week 12 (all machines excluding chest and LP).

RPE group. The essence of the RPE method is that training loads are increased when the exerciser perceives a given load to fall below a predetermined level of difficulty (29). The primary benefit of the RPE method is that it ensures all subjects complete each set without reaching the point of muscular failure, thereby reducing the risk of injury and muscle soreness (4). 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 the difficulty level of each exercise using the same scale used in the familiarization phase (30). The scale was visible to participants at all times, and training loads were increased for a given exercise when subjects reported an RPE ≤ 8 on consecutive days.

Repetitions in reserve group. The repetitions in reserve (RiR) method is identical to the repetition maximum (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, in other words, when they feel they have only one repetition "left in reserve" (31,32). Participants were instructed to stop each set when they had completed seven repetitions or when they felt they had one only one repetition "left in reserve" (whichever came first), thus eliminating the possibility of training to the point of failure. Training loads were increased when the participant could complete all sets of seven repetitions with at least one repetition left in reserve on consecutive workouts. The starting load for each exercise was the load used in the final familiarization session.

Warm-up and cooldown. Each session began with one warm-up set on the LP (six to eight repetitions at 50% initial working load) and one warm-up set on the seated CP (six to eight repetitions at 50% initial working load). Participants were also given the option of a 5-min warm-up or cooldown on a treadmill or cycle ergometer before and after each training session, although the majority of subjects did not make use of this option.

Enjoyment and perceived tolerance. Enjoyment and perceived tolerance were assessed at the end of each training session using a previously published survey (3). Using a seven-point Likert scale, subjects were instructed to indicate the degree to which they agreed with the following two statements: "I have found today's exercise session to be enjoyable" and "I have found today's exercise session to be tolerable." Subjects were only identified by group on their survey forms to ensure anonymity, and completed surveys were deposited into a locked letterbox. Minimal clinically important difference thresholds (MCID) between groups were computed as 0.2 × pooled SD of the group survey responses (33).

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 AE are of equal impact, a weighting system was utilized to give greater emphasis to more serious AE. Incidences of residual muscle soreness with no reduction in training load were counted as one weighted AE (WAE) per session, AE requiring a reduction in training load were counted as two WAE per session, and AE causing an exercise session to be postponed were counted as three WAE. An AE causing the subject to drop out of the study completely was considered three WAE 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 AE.

Statistical analysis. Baseline differences in age, body mass index, training experience, LP 1RM, and CP 1RM were assessed using multiple one-way ANOVA. Between-group differences in muscular strength and functional improvement over the course of the study were assessed using multiple one-way ANCOVA, controlling for pretest values. *Post hoc* pairwise comparisons were conducted using a Bonferroni correction and, if necessary, nonparametric analysis used to address nonnormal data distributions. Using G*Power (34), an estimated effect size (Cohen's f) of 0.45 was identified from an analysis of relevant previous literature. Under an alpha level of 0.025 (two-tailed), a required sample size of 68 was identified as necessary to obtain a statistical power of 0.80. Adjusting for an anticipated drop-out rate of 19% (3), 80 participants were identified as necessary (20 per group).

RESULTS

Strength and functional measures. Demographic statistics by group and by total cohort are presented in Table 1. No significant between-group differences ($P < 0.05$) 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, AE, and functional performance over the course of the study are presented in 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 [$F(3,67) = 29.3$, $P \leq 0.001$, 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 ± 2.1 kg, $P \leq 0.001$; mean difference (SE) = 13.6 ± 2.1 kg, $P \leq 0.001$, respectively] and RPE [mean difference (SE) = 12.1 ± 2.0 kg, $P \leq 0.001$;

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TABLE 2. Pretest and posttest 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)	Posttest (*n* = 17)	Baseline (*n* = 20)	Posttest (*n* = 16)	Baseline (*n* = 21)	Posttest (*n* = 20)	Baseline (*n* = 20)	Posttest (*n* = 20)	Baseline (*n* = 82)	Posttest (*n* = 73)
LP 1RM (kg)	154.8 (57.1)	181.2 (65.0)*	145.1 (42.3)*	167.6 (57.2)*	148.1 (49.0)	173.6 (49.4)*	147.7 (48.0)	170.7 (62.1)*	149 (49.2)	173.3 (57.1)*
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 pretest values ($P < 0.05$).
ATL, average training load; WS, walking speed; TUG, timed up and go; GJ, gallon jug shelf transfer test; STS, 30-s sit-to-stand test.

mean difference (SE) = 8.0 ± 2.1 kg, $P = 0.002$, respectively] groups. In terms of relative (percent) improvement over the course of the study, we observed the following changes as reported by group (RiR, %1RM, RM, RPE) and by total cohort: LP 1RM: +17.1%, +15.6, +17.3, +15.6, +16.3; CP 1RM: +18.5, +17.2, +12.6, +12.3, +14.6; average training load (kg): +51.1, +15.3. +56.5, +27.7, +36.6; usual walking speed (s): 0.0, −5.1, −2.6, −2.6, 0.0; maximum walking speed (s): −3.6, 0.0, 0.0, −7.7, −3.8; timed up and go (s): −3.2, −8.5, −4.9, −8.2, −6.6; gallon jug transfer test: −4.4, −7.1, −5.8, −8.9, −6.8; 30-s sit to stand: +8.6, +9.9, +9.1, +2.6, +6.8.

Adverse events. No significant between-group differences were observed in the number of weighted AE 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.

Enjoyment. Between-group differences in enjoyment were analyzed under a nonparametric model due to the 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 [χ^2 (3) = 64.83, $P < 0.001$, Cohen's $f = 0.23$], with responses (mean ± SD) on a 7-point Likert scale averaging 6.36 ± 0.84, 6.14 ± 1.13, 5.98 ± 1.31, and 6.62 ± 0.83, for the RiR, %1RM, RM, and RPE groups, respectively 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, $U = 44{,}009.00$, $P \leq 0.001$; %1RM: mean difference = 0.48, $U = 36{,}238.00$, $P \leq 0.001$; RM: mean difference = 0.64, $U = 44{,}794.50$, $P \leq 0.001$]. All significant between-group differences exceeded the computed MCID values. No significant pairwise differences in enjoyment were found between any other groups (RiR, %1RM, RM).

Perceived tolerance. Evaluation of between-group differences in perceived tolerance was conducted under a nonparametric model due to nonnormality 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 [χ^2 (3) = 109.78, $P < 0.001$, Cohen's $f = 0.27$], with responses (mean ± SD) on a 7 point Likert scale averaging 6.38 ± 0.78, 6.13 ± 1.11, 6.10 ± 1.12, and 6.74 ± 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 0.0083 ($P = 0.05/6$). 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, $U = 39{,}365.50$, $P \leq 0.001$; %1RM: mean difference = 0.61, $U = 30{,}285.00$, $P \leq 0.001$; RM: mean difference = 0.64, $U = 39{,}376.50$, $P \leq 0.001$]. Once again, all significant between-group differences exceeded the computed MCID values. No other significant differences in perceived tolerance were found between any other combination of groups (RiR, %1RM, RM).

Adherence. From the 82 people who successfully completed the 2-wk familiarization and pretesting phase, 71 completed the study in its entirety and two dropouts returned for posttesting. Five 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 posttesting status can be found in Figure 1.

Despite indicating on the preparticipation 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-wk period; $n = 55$), late compliers (completed all 22 training sessions in >9 wk; $n = 12$), or partial compliers (did not complete all training sessions; $n = 5$). Partial compliers consisted of two dropouts who returned for posttesting, 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' noncontinuous participation had a skewing effect on the overall results of the study, multiple ANCOVA, controlling for pretest values, were run to see if any significant differences existed between total, late, and partial compliers with respect to posttest strength and functional measures. No differences were identified and no further distinction was made in the analysis based on complier type.

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, and %1RM methods. Although higher tolerance and enjoyment when using the RPE method is supported theoretically, to our knowledge, this is the first study to quantify these differences in an older population.

Given our results, the RPE method appears to be the optimal load progression technique for strength training of older adults, since they are likely to find it significantly more tolerable and enjoyable, yet no less efficacious than the RM, %1RM, or RiR methods. As discussed in the Introduction, individuals who find exercise more tolerable and enjoyable are significantly more likely to continue on a long-term basis (1). Additionally, although differences in WAE did not reach the level of statistical significance, the fact that subjects in the RPE group (2.3 ± 3.6) averaged less than half the number of WAE than subjects in the RiR (5.8 ± 8.7) and RM groups (5.7 ± 7.7) should be considered. As noted by Shaw et al. (35), injury resulting from physical conditioning is an important deterrent in continuing an exercise regimen.

RM method. Subjects in the RM group experienced significant improvements in upper- and lower-body maximum strength comparable to those previously reported (8,36), as well as improvements in average training load, gallon jug transfer test, and 30-s 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 (5), 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 AE. 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 the RM method was found to be no more effective than the RiR, RPE, and %1RM methods at improving muscular strength and function, but was perceived as significantly less tolerable and enjoyable, we conclude that the RM approach to load progressions is not optimal for use with an older population.

%1RM method. The main reason why the %1RM method has been theorized to be optimal for older adults is that it may be most effective at producing the greatest increases in maximal muscular strength (37). 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 underestimation of the appropriate workload and potentially attenuate the magnitude of their realized strength gains. One concern when using the %1RM method in older adults is that it is time consuming, as dedicated sessions must be conducted to determine the 1RM for each exercise. For untrained individuals, the need to frequently reestablish 1RM may be particularly laborious given that this population is known to experience rapid strength gains in the early stages of a new RT program (4,38).

Subjects in this group experienced significant improvements in upper- and lower-body maximum strength that were similar to those reported in other studies using this progression technique (39,40). 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 (37) 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. Again, we conclude that the %1RM method does not appear to be the best choice for use in strength training in older adults.

RiR method. The RiR method was of considerable interest because it was supported by the smallest volume of literature; but appeared to offer a unique compromise between the RM and RPE methods (3). Instructing subjects to stop when they had one RiR eliminated the apprehension associated with 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 (32). A significant limitation to the use of the RiR method in older adults is the low number of available studies (32,41), 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 left "in reserve" (32,41).

Subjects in this group experienced significant improvements in strength and functional performance comparable to those seen in two previous studies with the same population (32,41). The RiR 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. This group had the second-highest number of dropouts at four; however, only one participant conveyed a reason related to the study.

RPE method. The RPE method may be the most efficacious for use with older adults as it allows 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 may be perceived as the least intimidating of all progression methods tested. 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 increasing program intensity too quickly (4,42). The RPE method is limited, however, in that it requires exercisers to be familiar with the scale being used and also requires the documentation of RPE values from one session to the next.

Because the RPE method relies on subjective assessments of difficulty, rather than an objective performance criterion as used 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 those seen in 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.

New methods for monitoring RT intensity in older adults. Near the end of article preparation for the current study, a branch of research was brought to our attention using the Feeling Scale (FS) to regulate exercise intensity in physical activity and aerobic training. Although we agree the FS and other self-pacing strategies (43) may have particular utility in regulating RT in older adults, to date they have not been used extensively in the literature. Given that the primary objective of this investigation was to compare the relative efficacy of the progression methods most-commonly used in existing research, extensive incorporation of self-pacing measures, such as the FS, were not included. However, given that an older adult's subjective experience of perceived difficulty is a primary driver of whether they will continue to RT, we think these approaches may be viable for use with an older population.

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.

A second limitation was our decision to omit the overhead (shoulder) press, because the minimum load on this machine (18 lb) was above the 1RM of our most inexperienced subjects. A third 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 individuals, 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. One such individual, for example, had to withdraw from the study because he sustained a serious muscle strain. It is possible that for individuals predisposed to give a maximum effort in each session, a method, such as RPE or RiR, could reduce the potential for injury.

Additionally, the positively skewed responses that were observed for enjoyment and perceived tolerance could be a limitation of these scales, and we would encourage future researchers to select an assessment tool that is less likely to elicit clustered responses at the highest possible answer.

Lastly, although not the central emphasis of the investigation, we feel the quality of the investigation may have been increased had we elected to include one or more measures of cardiometabolic health, such as blood pressure or cholesterol. Such measurements would strengthen our ability to create balanced groups at baseline and could also provide valuable insight into our findings when used as a covariate.

CONCLUSION

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 RT for older adults. Higher-intensity methods, such as the RM and RiR, thought to lead to greater strength improvement due to higher intensities, did not produce greater strength improvement than the RPE method and were perceived to be significantly less tolerable and enjoyable, to levels that exceeded the computed MCID threshold. In other words, the increased effort associated with the RM, RiR, and %1RM methods does not appear to lead to improved outcomes; therefore, the rationale for their use in RT for older adults is debatable over the course of a short-to-medium term RT program lasting up to 12 wk.

Lastly, despite the finding that the RPE method appears to be the ideal progression method to use in an RT program for older adults, it must be acknowledged that it is unclear whether these findings hold true over the course of an extended training period lasting multiple months or years. Indeed, it has been suggested by at least one researcher that the specific details of an older adult's RT program (i.e., high vs low load, fast vs slow velocity) do not begin to exert an influence on the type and magnitude of neuromuscular adaptation for at least 6 months (7). This means that the possibility cannot be discounted that after half a year or more of regular strength training, one or more of the RiR, RM, or %1RM methods may begin to facilitate significantly greater strength gains than the RPE method, or no longer be perceived as less tolerable or enjoyable. Subsequent researchers will need to establish whether our findings remain valid over the course of a longer-term study.

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REFERENCES

1. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc*. 2009;41(7):1510–30.
2. Kraemer WJ, Adams K, Cafarelli E, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2002;34(2):364–80.
3. Conlon JA, Haff GG, Tufano JJ, Newton RU. Training load indices, perceived tolerance, and enjoyment among different models of resistance training in older adults. *J Strength Cond Res*. 2017;32(3):867–75.
4. Balachandran AT, Gandia K, Jacobs KA, et al. Power training using pneumatic machines vs. plate-loaded machines to improve muscle power in older adults. *Exp Gerontol*. 2017;98(1):134–42.
5. Davies T, Orr R, Halaki M, Hackett D. Effect of training leading to repetition failure on muscular strength: a systematic review and meta-analysis. *Sports Med*. 2016;46(4):487–502.
6. Willardson J, Norton L, Wilson G. Training to failure and beyond in mainstream resistance exercise programs. *J Strength Cond Res*. 2010;32(3):21–30.
7. DeBeliso M, Harris C, Spitzer-Gibson T, Adams KJ. A comparison of periodised and fixed repetition training protocol on strength in older adults. *J Sci Med Sport*. 2005;8(2):190–9.
8. Conlon JA, Newton RU, Tufano JJ, et al. The efficacy of periodised resistance training on neuromuscular adaptation in older adults. *Eur J Appl Physiol*. 2017;117(6):1181–94.
9. Rhodes RE, Martin AD, Taunton JE, et al. Factors associated with exercise adherence among older adults. An individual perspective. *Sports Med*. 1999;28(6):397–411.
10. Van Roie E, Bautmans I, Coudyzer W, Boen F, Delecluse C. Low- and high-resistance exercise: long-term adherence and motivation among older adults. *Gerontology*. 2015;61(6):551–60.
11. Brassington GS, Atienza AA, Perczek RE, DiLorenzo TM, King AC. Intervention-related cognitive versus social mediators of exercise adherence in the elderly. *Am J Prev Med*. 2002;23(2 Suppl):80–6.
12. Dishman RK. Motivating older adults to exercise. *South Med J*. 1994; 87(5):S79–82.
13. Sidney KH, Shephard RJ. Attitudes towards health and physical activity in the elderly. Effects of a physical training program. *Med Sci Sports Exerc*. 1976;8(4):253–7.
14. Thompson C, Wankel L. The effects of perceived activity choice upon frequency of exercise behavior. *J Appl Soc Psychol*. 1980;10: 436–43.
15. Ekkekakis P, Parfitt G, Petruzzello SJ. The pleasure and displeasure people feel when they exercise at different intensities: decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Med*. 2011;41(8):641–71.
16. Holsgaard Larsen A, Caserotti P, Puggaard L, Aagaard P. Reproducibility and relationship of single-joint strength vs multi-joint strength and power in aging individuals. *Scand J Med Sci Sports*. 2007;17(1): 43–53.
17. Rydwik E, Karlsson C, Frandin K, Akner G. Muscle strength testing with one repetition maximum in the arm/shoulder for people aged 75 + − test–retest reliability. *Clin Rehabil*. 2007;21(3):258–65.
18. Phillips WT, Batterham AM, Valenzuela JE, Burkett LN. Reliability of maximal strength testing in older adults. *Arch Phys Med Rehabil*. 2004;85(2):329–34.
19. Pollock ML, Carroll JF, Graves JE, et al. Injuries and adherence to walk/jog and resistance training programs in the elderly. *Med Sci Sports Exerc*. 1991;23(10):1194–200.
20. Bellew J. Older adults and one-repetition maximum testing: what about injuries? *Strength Cond J*. 2002;24(1):60–2.
21. Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol*. 1988;64(3):1038–44.
22. Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians. Effects on skeletal muscle. *JAMA*. 1990; 263(22):3029–34.
23. Rooks DS, Kiel DP, Parsons C, Hayes WC. Self-paced resistance training and walking exercise in community-dwelling older adults: effects on neuromotor performance. *J Gerontol A Biol Sci Med Sci*. 1997;52(3):M161–8.
24. Hazell T, Kenno K, Jakobi J. Functional benefit of power training for older adults. *J Aging Phys Act*. 2007;15(3):349–59.
25. Henwood TR, Riek S, Taaffe DR. Strength versus muscle power-specific resistance training in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci*. 2008;63(1):83–91.
26. Roberson KB, Potiaumpai M, Widdowson K, et al. Effects of high-velocity circuit resistance and treadmill training on cardiometabolic risk, blood markers, and quality of life in older adults. *Appl Physiol Nutr Metab*. 2018;43(8):822–32.
27. Buskard A, Zalma B, Cherup N, et al. Effects of linear periodization versus daily undulating periodization on neuromuscular performance and activities of daily living in an elderly population. *Exp Gerontol*. 2018;113:199–208.
28. Kraemer W, Ratamess N. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc*. 2004; 36(4):674–88.
29. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377–81.
30. Robertson RJ, Goss FL, Rutkowski J, et al. Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Med Sci Sports Exerc*. 2003;35(2):333–41.
31. Helms ER, Cronin J, Storey A, Zourdos MC. Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. *Strength Cond J*. 2016;38(4):42–9.
32. Zourdos MC, Klemp A, Dolan C, et al. Novel resistance training-specific rating of perceived exertion scale measuring repetitions in reserve. *J Strength Cond Res*. 2016;30(1):267–75.
33. Swinton PA, Hemingway BS, Saunders B, Gualano B, Dolan E. A statistical framework to interpret individual response to intervention: paving the way for personalized nutrition and exercise prescription. *Front Nutr*. 2018;5.
34. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods*. 2009;41(4):1149–60.

35. Shaw CE, McCully KK, Posner JD. Injuries during the one repetition maximum assessment in the elderly. *J Cardiopulm Rehabil Prev*. 1995;15(4):283–7.
36. Prestes J, da Cunha Nascimento D, Tibana RA, et al. Understanding the individual responsiveness to resistance training periodization. *Age*. 2015;37(1):55–68.
37. Lopez P, Izquierdo M, Radaelli R, et al. Effectiveness of multimodal training on functional capacity in frail older people: a meta-analysis of randomized controls trials. *J Aging Phys Act*. 2017;26(3):1–36.
38. Ni M, Signorile JF, Mooney K, et al. Comparative effect of power training and high-speed yoga on motor function in older patients with Parkinsons disease. *Arch Phys Med Rehabil*. 2016;97(3):345–54. e15.
39. Reid KF, Callahan DM, Carabello RJ, et al. Lower extremity power training in elderly subjects with mobility limitations: a randomized controlled trial. *Aging Clin Exp Res*. 2008;20(4):337–43.
40. Marsh AP, Miller ME, Rejeski WJ, Hutton SL, Kritchevsky SB. Lower extremity muscle function after strength or power training in older adults. *J Aging Phys Act*. 2009;17(4):416–43.
41. Ormsbee MJ, Carzoli JP, Klemp A, et al. Efficacy of the repetitions in reserve-based rating of perceived exertion for the bench press in experienced and novice benchers. *J Strength Cond Res*. 2019;33(2): 337–45.
42. Tiggemann CL, Korzenowski AL, Brentano MA, et al. Perceived exertion in different strength exercise loads in sedentary, active, and trained adults. *J Strength Cond Res*. 2010;24(8): 2032–41.
43. Williams DM, Dunsiger S, Jennings EG, Marcus BH. Does affective valence during and immediately following a 10-min walk predict concurrent and future physical activity? *Ann Behav Med*. 2012; 44(1):43–51.

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