Physiological and Functional Responses to Low-Moderate Versus High-Intensity Progressive Resistance Training in Frail Elders

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Background. The purpose of this efficacy study was to measure the dose–response effect of a free weight-based resistance training program by comparing the effects of two training intensities (low-moderate and high) of the knee extensor (KE) muscles on muscle function, functional limitations, and self-reported disability.

Methods. The authors conducted a single-blinded, randomized, placebo-controlled trial. Twenty-two institutionalized elders (mean age, 81.5 years) were assigned to either high-intensity strength training (HI; n = 8), low-moderate intensity strength training (LI; n = 6), or weight-free placebo-control training (PC; n = 8). The HI group trained at 80% of their 1-repetition maximum and the LI group trained at 40%. All groups performed 3 sets of 8 repetitions, 3 times per week for 10 weeks. Outcome measures included KE maximal strength, KE endurance, and functional performance as assessed by 6-minute walking, chair-rising, and stair-climbing tests, and by self-reported disability.

Results. KE strength and endurance, stair-climbing power, and chair-rising time improved significantly in the HI and LI groups compared with the PC group. Six-minute walking distance improved significantly in the HI group but not in the LI group compared with the PC group. Changes observed in HI were significantly different from those observed in the LI group for KE strength and endurance and the 6-minute walking test, with a trend in the same direction for chair-rising and stair-climbing. Changes in strength were significantly related to changes in functional outcomes, explaining 37% to 61% of the variance.

Conclusions. These results show strong dose–response relationships between resistance training intensity and strength gains, and between strength gains and functional improvements after resistance training. Low-moderate intensity resistance training of the KE muscles may not be sufficiently robust from a physiologic perspective to achieve optimal improvement of functional performance. Supervised HI, free weight-based training for frail elders appears to be as safe as lower intensity training but is more effective physiologically and functionally.

ONE of the first noticeable effects of aging is the decline in muscle mass and strength. These impairments have been associated with loss of functional capacity and increased risk for falling (1). Skeletal muscle adaptation to resistance training has been shown to be well preserved in older compared with younger persons (2). High-intensity (HI) resistance training is a safe and effective method to enhance muscle strength and mass (3–5).

High-intensity resistance training may not be available in all types of facilities because of lack of equipment, lack of space, cost, or reluctance of caregivers to prescribe this mode of training. Therefore, some authors have compared low-moderate intensity (LI) training to HI regimens (6–8), and they have found significant effects of the lower intensity of training on several parameters linked to muscle function and composition (6,7). Vincent and colleagues (8) found no significant difference between machine-based training at 50% or 80% of the 1-repetition maximum (1RM) in healthy older adults with respect to changes in strength, endurance, and stair-climbing ability, although the volume of exercise was greater in the LI group. Yet, to our knowledge, the comparative effects of these 2 training intensities have never been quantified in a population of frail adults using the same volume of exercise. In addition, comparative benefits on functional limitations or disability have not been reported. Thus, we hypothesized that dose–response effects of resistance training could be shown when optimal techniques were used, and we compared the effects of 2 intensities of resistance training (LI and HI) of the knee extensor (KE) muscles on muscle function, functional limitations, and self-reported disability.
METHODS

Participants and Design

Participants were recruited through advertisements and visits among the residents of public nursing homes administered by the Center of Social Action of Nice, France. Eligible volunteers were at least 70 years old and were ambulatory (that is, they could walk without the assistance of another person for a distance of at least 20 meters) and able to understand simple instructions. Participants were enrolled after an assessment and a physical examination screening for exclusion criteria as follows: (a) cognitive impairment precluding understanding of the written informed consent; (b) practice of regular exercise outside of the research activities; (c) unstable cardiovascular disease, hypertension, diabetes, or any other unstable medical condition; (d) amputations; (e) hernias; (f) symptomatic known unrepaired aortic aneurysm; (g) recent (within 6 months) hospitalization for myocardial infarction, stroke, fracture, eye surgery, or laser treatment; (h) skin disease precluding placement of ankle weights; (i) musculoskeletal deformity; (j) neuromuscular disease; and (k) symptomatic rheumatoid or osteoarthritis precluding planned exercises. Data concerning number of falls in the past year and number of diagnosed diseases were collected from the medical records of each participant as baseline characteristics. This study was approved by the advisory committee of Nice for the protection of persons involved in biomedical research. All participants gave their written informed consent. After baseline assessments, stratified randomization was performed on ranked baseline 1RM values, and participants were randomly assigned to 1 of 3 intervention groups: HI strength training, LI strength training, or weight-free placebo-control training (PC).

Outcome Measures

The primary outcome of this study was KE muscle strength, and secondary outcomes were functional limitations and self-reported disability. All tests were monitored by the same investigator and were single blinded (the participants were not aware of the study hypotheses or to which group they were randomized).

Muscle strength and endurance.—All testing was performed unilaterally (dominant side) using adjustable ankle cuffs (Australian Barbell Company, Melbourne, Australia). To standardize the test (because the size of the chairs did not fit every participant), volunteers were seated on a table, with thighs strapped to the table, and knees bent at 90°. During the test, the participant was instructed to fold his or her arms across the chest. One investigator supported the participant’s back so that the hip angle was maintained at 90°. An electronic goniometer (Biopac Systems, Santa Barbara, CA) was used to monitor the range of motion and to check that the full extension was obtained. The axis of rotation of the goniometer was adjusted at the knee joint, with the arms aligned to the lateral malleolus and greater trochanter. Maximum dynamic concentric strength of the KE muscles was assessed as the maximal weight that could be lifted 1 time only within 3 degrees of the full range of motion, or the 1RM (9). Before weighting the ankle, the participant’s unweighted range of motion during knee extension was recorded once with the goniometer. This unweighted range of motion was used to determine the success of each weighted lift. The 1RM was obtained with the 2-failure criteria in 5 or 6 attempts, with 1 minute of rest between trials. To minimize learning-related improvements, after 1 familiarization session, baseline 1RM was tested twice (1 week apart), and the best of the 2 measures was used in subsequent analyses. The coefficient of variation of 1RM testing using this method in our laboratory is 8.4%. Subsequently, the 1RM was tested only once. Muscle endurance was determined as the number of sequential repetitions that could be completed in the full range of motion without pausing, at a fixed load of 90% of the baseline 1RM. Failure was considered the inability to complete a full extension to within 3 degrees of the unweighted range of motion (10,11).

Functional limitations.—Functional limitation measures, based on leg extension power, were adapted from previous studies (3,11,12), and tests were shown to the participants in a familiarization session. The 6-minute walking test is related to several physiologic and functional domains in older adults (13,14). Therefore, we used the 6-minute walking test as an overall index of functional limitations.

Chair-rising test.—Participants were asked to rise from a chair to a full standing position as rapidly as possible. Seats of the chairs, which had arms, were 0.43 meter high. The investigator measured the time taken to the full stance position during 3 trials, with 2 minutes of rest between trials, and the best result was used for the analysis. Participants were allowed to use their arms only if they could not stand without using them.

Stair-climbing test.—Participants were required to climb 4 risers of stairs as fast as possible without using a handrail. Risers were 0.15 meter high and 0.30 meter long (horizontal length), so that the total height was 0.6 meter and the total horizontal distance was 1.2 meters. Two minutes of rest was allowed between trials, and the best time of 3 trials was used in the analyses. Stair-climbing power (force × distance/time) was defined as body weight × vertical height climbed/time to ascend steps, and was expressed in watts.

Six-minute walking test.—Overall functional limitation was assessed using the 6-minute walking test (15). The participants were asked to walk for 6 minutes along a 15-meter corridor, covering as much ground as possible. Participants were allowed to use an assistive device and could stop to rest if necessary, but they were asked to resume walking as soon as possible.

Self-reported functional difficulty.—Self-reported functional difficulty was assessed using the French version (16) of the Health Assessment Questionnaire, Disability Index subscale (17). This questionnaire was initially developed for persons with rheumatism. The Disability Index assesses 8 categories of dressing, arising, eating, walking, hygiene,
reach, grip, and common daily activities. Participants are asked to report the amount of difficulty they have in performing activities using ratings without any difficulty, with some difficulty, with much difficulty, and unable to do, without the assistance of another person or device. High scores (ranging from 0 to 3) indicate the most disabled status. The score for each category is the highest score reported for any component question of this category. According to the standard scoring method, the score of each category was adjusted if the participant was assisted by a device or another person, by being automatically set to 2, unless it was already 3. The overall disability score was then obtained by averaging the 8 subscale scores.

Resistance Training
The training protocol consisted in a 10-week classical progressive resistance training (18) of the KE muscles, 3 days per week. Because we aimed to specifically compare the dose–response effects of 2 training intensities, the HI, LI, and PC groups trained at the same volume: 3 sets of 8 repetitions with 6 to 8 seconds for each repetition and 1 to 2 minutes of rest between sets. Participants of the HI and the LI groups trained, respectively, at 80% and 40% of their 1RM, with the same adjustable ankle cuff system used for strength testing. The PC group wore empty ankle cuffs during sessions throughout the 10-week intervention period. Maximal leg extension strength of both groups (HI and LI) was assessed weekly during a training session, and the evaluation was counted as 1 set. Training weights were adjusted as appropriate to maintain the target training intensities. Participants in the PC group performed the same exercises, but without resistance other than the empty cuffs (300 g) and did not have interim 1RM testing. The same investigator conducted all the training sessions. Participants were trained in 2 different groups: 1 PC group, without resistance other than the empty ankle cuffs, and 1 weighted group, including both high and low-moderate intensities.

Statistical Analyses
All data were analyzed using Statistica 5.0 software (StatSoft, Inc., Tulsa, OK). Data were first evaluated visually and statistically for normality of distribution. Data are presented as the mean ± standard error of the mean (SEM) for normally distributed data. Baseline values were compared between groups with an analysis of variance for normally distributed data or a Kruskal-Wallis analysis of variance for ranked data, as appropriate. Relationships between variables of interest were determined using the Pearson correlation coefficient. Changes in variables over time were analyzed for effects of time and group-by-time interactions using a repeated-measures analysis of variance. A post hoc Student-Newman-Keuls test was used on factorial analysis of covariance models (adjusted for baseline values) of percentage change in the dependent variable, for which a significant time-by-group interaction was identified with repeated-measures analysis of variance models. Power calculations performed a priori indicated that 18 participants would be needed to identify a difference of 25% between the HI and LI groups, with alpha set at 0.05 and beta at 0.20.

RESULTS
Recruitment Results
Thirty-nine participants volunteered to participate in the program, and of those, 7 did not meet the eligibility criteria or could not meet the study requirements. Among the remaining participants, 5 were no longer eligible because of medical exclusion criteria. Therefore, 27 participants were initially enrolled and randomized. Two of them dropped out during the study for personal reasons and 3 because of medical reasons not related to the study (hospitalization for undernutrition and gastrointestinal problems). Twenty-two participants completed the program.

There were no exercise or testing-related injuries during the study, nor were there any other medical complications or study-related adverse events. The compliance rate was 99% in the 2 exercise groups and 89% in the control group.

Participant Characteristics
Table 1 shows the baseline characteristics of the recruited participants. There were no significant differences between groups in any of these characteristics.

Muscle Strength
Baseline 1RM was significantly related to muscle endurance (r = .45, p = .0368), 6-minute walking distance (r = .61, p = .0027), chair-rising time (r = -.49, p = .0194), stair-climbing power (r = .56, p = .0064), and disability (r = -.71, p = .0002). Muscle strength improved significantly over time in the cohort (p < .0001), and we noted a group-by-time interaction, with a significantly greater improvement in the HI (57.3 ± 4.8%) compared with the LI (36.6 ± 5.9%) group (p = .0001) (Table 2, Figure 1). Results in both groups were significantly different than those in the PC group (p < .001), and those of the HI and LI groups were significantly different from each other (p = .001). Changes in muscle strength were significantly related to changes in muscle endurance (r = -.88, p < .0001), 6-minute walking distance (r = .78, p < .0001), chair-rising time (r = -.61, p = .0024), and stair-climbing power (r = .68, p = .0004), with a trend toward this relationship for overall disability score (r = -.31, p = .161). The calculation of the correlation coefficient (r²) of each relationship indicated that strength change explained 61% of the variance in the 6-minute walking distance, 37% of the variance in chair-rising time, and 46% of the variance in stair-climbing power.

Muscle Endurance
Muscle endurance was significantly related to muscle strength (r = .45, p = .0368) but not to functional limitation or disability measures (data not shown). Muscle endurance increased significantly (p < .0001) in the LI (117.7 ± 33.1% [SEM]) and HI (284.6 ± 73.5%) groups and did not improve in the PC group (−1.7 ± 7.6%) (Table 2, Figure 1). Post hoc testing on the analysis of covariance model of percentage changes indicated that the HI and LI groups were significantly different from the PC group (respectively, p = .0003 and p = .048). The HI group was significantly better than the LI group for this outcome (p = .008).
**Functional Performance**

All functional limitation outcomes were significantly associated with each other. Baseline stair-climbing power was related to 6-minute walking distance ($r = .81, p < .001$) and inversely related to chair-rising time ($r = -.64, p = .001$), and 6-minute walking distance was inversely related to chair-rising time ($r = -.57, p = .005$). There were significant group × time interactions for all 3 tests (Table 2). Post hoc tests on the analysis of covariance model of percentage change scores showed that stair-climbing power improved and chair-rising time decreased significantly in both HI (respectively, $p = .008$ and $p = .0002$) and LI ($p = .009$ and $p = .0003$) groups but were not significantly different from each other (Figure 2). Six-minute walking distance improved significantly in the HI group compared with the LI group ($p = .01$) and the PC group ($p < .001$). The LI group was not different from the PC group for this outcome.

**Disability**

Baseline self-reported disability was significantly associated with muscle strength ($r = -.71, p = .0002$), 6-minute walking distance ($r = -.71, p < .001$), chair-rising time ($r = .50, p = .019$), and stair-climbing power ($r = -.57, p = .006$), with a nonsignificant trend for muscle endurance ($r = -.36, p = .103$). There was an improvement over time in overall disability scores ($p < .046$), and a trend for a group by time interaction ($p < .073$) (Table 2).

**DISCUSSION**

The primary finding of this study is that physiologic capacity (muscle strength and endurance) and 6-minute walking distance increased significantly more after HI resistance training than after LI training, with a trend in the same direction for other measures of functional limitations (chair-rising time and stair-climbing power). These results indicate a dose–response relationship between the intensity of training and strength improvements, and between strength gains and functional performance. Thus, the data support our hypothesis that higher intensity training results in greater physiologic gains and functional improvements in frail elders. Previous work has shown that functional status in elderly persons is associated with muscle endurance (10) in addition to other physiologic characteristics. Therefore, our findings that muscle endurance increased significantly more in the HI than in the LI group, analogous to the findings with muscle strength, may have benefit for other tasks of daily living that require a longer duration of muscular exertion than those measured in this study.

Importantly, the current trial was designed with free weights rather than machines, because the public health dissemination of resistance training would more likely

### Table 1. Baseline Characteristics (± SEM) of the Participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Sample</th>
<th>HI</th>
<th>LI</th>
<th>PC</th>
<th>$p$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>22</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>81.5 ± 1.4</td>
<td>83.3 ± 2.8</td>
<td>80.7 ± 2.3</td>
<td>80.3 ± 2.0</td>
<td>.63</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.2 ± 2.8</td>
<td>63.3 ± 5.0</td>
<td>62.5 ± 4.1</td>
<td>66.4 ± 5.3</td>
<td>.84</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>25.4 ± 1.0</td>
<td>24.3 ± 1.8</td>
<td>26.5 ± 1.4</td>
<td>25.5 ± 2.0</td>
<td>.72</td>
</tr>
<tr>
<td>Muscle strength (kg)</td>
<td>6.9 ± 0.4</td>
<td>7.3 ± 0.8</td>
<td>7.2 ± 0.7</td>
<td>6.1 ± 0.6</td>
<td>.42</td>
</tr>
<tr>
<td>Muscle endurance*</td>
<td>6 ± 0</td>
<td>6 ± 1</td>
<td>6 ± 1</td>
<td>6 ± 1</td>
<td>.94</td>
</tr>
</tbody>
</table>

**Functional capacity**

- Chair-rising time (s): 1.06 ± 0.09 0.98 ± 0.11 0.93 ± 0.05 1.25 ± 0.20 .30
- Stair-climbing power (W): 134.71 ± 11.09 137.19 ± 16.8 132.72 ± 14.26 133.71 ± 24.78 .99
- 6-minute walk distance (m): 176.6 ± 11.6 176.8 ± 16.8 169.3 ± 21.2 182.0 ± 24.0 .92
- Disability$: 0.90 ± 0.17 0.77 ± 0.25 1.08 ± 0.43 0.89 ± 0.27 .78
- Number of chronic diseases: 2.3 ± 0.2 2.2 ± 0.2 2.7 ± 0.5 2.0 ± 0.2 .28

Notes: $^*$Assessed as the number of repetitions with a 90% of initial 1-repetition maximum load. $^1$Health Assessment Questionnaire Disability index (16,17).

SEM = standard error of mean; HI = high intensity; LI = low-moderate intensity; PC = placebo control.

### Table 2. Physiological and Functional Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>HI Baseline</th>
<th>HI Final</th>
<th>LI Baseline</th>
<th>LI Final</th>
<th>PC Baseline</th>
<th>PC Final</th>
<th>Time</th>
<th>Group × Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle strength (kg)</td>
<td>7.3 ± 0.8</td>
<td>11.3 ± 1.0</td>
<td>7.2 ± 0.7</td>
<td>9.7 ± 0.7</td>
<td>6.1 ± 0.6</td>
<td>6.1 ± 0.6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Muscle endurance</td>
<td>6 ± 1</td>
<td>20 ± 1</td>
<td>6 ± 1</td>
<td>13 ± 2</td>
<td>6 ± 1</td>
<td>6 ± 1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

**Functional limitation**

- Chair-rising time (s): 0.98 ± 0.11 0.71 ± 0.06 0.93 ± 0.05 0.72 ± 0.04 1.25 ± 0.20 1.29 ± 0.21 .0002 .0008
- Stair-climbing power (W): 137.19 ± 17.01 163.48 ± 21.28 132.72 ± 14.26 147.71 ± 14.61 133.71 ± 24.78 116.12 ± 22.48 .118 .003
- 6-minute walk distance (m): 176.8 ± 16.8 225.5 ± 21.8 169.3 ± 21.2 183.4 ± 24.0 182.0 ± 24.0 173.2 ± 19.1 .002 .0005
- Disability$: 0.77 ± .025 0.52 ± .21 1.08 ± .43 0.46 ± .28 0.89 ± .27 1.00 ± .33 .046 .073

Note: HI = high intensity; LI = low-moderate intensity; PC = placebo control.
involve this cost-effective approach to training. The magnitude of these improvements (57 ± 5%, HI; 37 ± 6%, LI) is as high as that reported after many experimental studies using weight machines in older adults for similar periods of time (20–22).

Our results differ from previous dose–response studies of training intensity in elderly persons. Authors including Taaffe and colleagues (6), Hortobagy and coworkers (7), or more recently Vincent and colleagues (8) have compared intensities of resistance training that were similar to ours (Table 3). None of these studies found significant differences in muscle strength after moderate-intensity or HI machine-based training ranging from 10 to 52 weeks in healthy elderly persons. However, these studies preclude conclusions based solely on the variable of interest, intensity, because the lower intensity was partly compensated for by increasing the volume of training (number of repetitions in these protocols). It is noteworthy that KE strength gains in these other studies were similar or lower to those we observed in our current investigation, despite the fact that we used free weights rather than machines. This may be explained by the use of nonoptimal training techniques such as the slow-progression model (6,7) or the single-set regimen (8). In contrast, we adjusted the intensity of exercise each week throughout the trial and used 3 sets per session.

Others have reported functional improvements after LI resistance training, but these studies have also included balance training (23,24) or involved several different exercises (8). Both our LI and HI regimens of resistance training exercise elicited similar and significant improvements in 2 measures of functional performance (stair-climbing and chair-rising). This finding would support the proposed curvilinear relationship between strength and function advanced by Buchner and colleagues (25), including previous findings showing a strength threshold below which functional performance is limited (19,26).

In contrast, the 6-minute walking distance, which has been conceptualized as an overall index of functional limitations (14), was improved only in the HI group and did not change in the LI group.
not change significantly in the LI group. Changes in muscle strength were significantly related to changes in functional performance in the entire cohort, and the strongest correlation was observed with the 6-minute walking distance change ($r = .78$, $p < .001$). Together, these analyses support the hypothesis that LI resistance training has less robust effects on functional impairments than does HI training.

As others have observed (27), baseline values of self-reported disability were significantly associated with lower-limb functional performance, and there was a trend for greater improvements in the HI group. The marginal significance for the disability outcomes after the current intervention is likely due to the small sample size and relatively narrow range of early disability present at baseline in the study cohort. In addition, we trained only 1 lower-extremity muscle group, and it is likely that residual muscle weakness in untrained muscles would explain the modest effect on disability. Finally, the causes of disability are clearly multifactorial, and our intervention did not, of course, address factors other than muscle dysfunction.

Limitations of the current study include the small sample size and relatively short duration of training. In addition, we did not include other factors that may have contributed to the improvements in functional limitations and disability, such as muscle power, psychological factors, or other changes in health status. Future studies should evaluate the long-term feasibility, safety, and efficacy of this mode of training; its utility in persons who are more frail; the minimum level of supervision required for adequate progression; and potential mediators and covariates of the observed functional benefits.

**Conclusion**

These results indicate strong dose–response relationships between resistance training intensity and strength–endurance gains, and between strength gains and functional improvements after resistance training. The magnitude of the strength gains after classical (slow velocity, high intensity) resistance training explains much of the exercise effect on functional performance. Low-moderate intensity resistance training of the KE muscles does not appear to be sufficiently robust from a physiologic perspective to optimally improve functional performance, and it does not appear to offer any advantages in terms of safety, efficacy, or acceptance when directly compared for the first time with HI training in frail elderly persons.

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**Table 3. Low-Moderate Versus High-Intensity Machine-Based Resistance Training Studies**

<table>
<thead>
<tr>
<th>Source</th>
<th>Participants</th>
<th>Leg Exercise Type</th>
<th>Intensity, 1RM Frequency of Testing</th>
<th>Frequency, Volume, Duration of Training</th>
<th>Knee Extension Strength Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taaffe et al. (6)</td>
<td>7, 65–79</td>
<td>Leg press Knee extension</td>
<td>40% 1RM, once/2–3 weeks 3 times/week 3 sets of 14 rep 52 weeks</td>
<td>60%* (50% after 12 weeks)</td>
<td></td>
</tr>
<tr>
<td>Hortobagyi et al. (7)</td>
<td>9, 66–83</td>
<td>Supine leg press</td>
<td>40% 1RM, once/2.5 weeks 3 times/week 5 sets of 8–12 rep 10 weeks</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Vincent et al. (8)</td>
<td>24, 60–83</td>
<td>Leg press Knee extension</td>
<td>50% 1RM, each session 3 times/week 1 set of 13 rep 24 weeks</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>Current study</td>
<td>6, 73–95</td>
<td>Knee extension</td>
<td>40% 1RM, once a week 3 times/week 3 sets of 8 rep 10 weeks</td>
<td>37%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8, 73–95</td>
<td>Knee extension</td>
<td>80% 1RM, once a week 3 times/week 3 sets of 8 rep 10 weeks</td>
<td>57%</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** *Estimated from graphic data.

$^{1}p < .01$, significantly different between groups.

1RM = 1-repetition maximum; rep = repetitions.

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REFERENCES