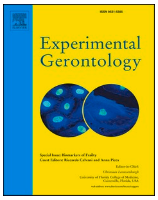
Experimental Gerontology 220 (2026) 113174

Contents lists available at ScienceDirect

Experimental Gerontology

journal homepage: www.elsevier.com/locate/expgero



Validity of the individualized load-velocity profile to predict one-repetition maximum on a pneumatic leg press device in adults aged 55–81 years

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ARTICLE INFO

Section Editor: Li-Ning Peng

Keywords:
Ageing
Muscle strength
Resistance training
Load-velocity profile

ABSTRACT

Introduction: Resistance exercise is the primary strategy to counteract age-related declines in muscle function. Training loads are typically prescribed relative to an individual's one-repetition maximum (1-RM), but direct 1-RM testing is time-consuming and may increase injury risk in older adults. Because movement velocity can predict relative load, this cross-sectional study examined the accuracy of 1-RM estimation from individual load-velocity (L-v) profiles.

Methods: Ninety-six participants (60 males, 36 females; 69 ± 5.8 years) performed unilateral explosive repetitions on a pneumatic leg press at five submaximal loads to generate individualized L-v equations, followed by single repetitions to determine 1-RM. The group's sex-specific average measured velocity at 1-RM (V_{1RM}; males: 0.17 ± 0.08 $m \cdot s^{-1}$, females: 0.18 ± 0.09 $m \cdot s^{-1}$) was defined. A corrected V_{1RM}, which accounted for non-linearity of the L-v relationship near maximal load, was also calculated (males: 0.31 ± 0.15 $m \cdot s^{-1}$, females: 0.33 ± 0.12 $m \cdot s^{-1}$). To estimate 1-RM, measured V_{1RM} and corrected V_{1RM} values were input into the individual L-v equations.

Results: Estimates based on measured V_{1RM} overestimated 1-RM (mean difference = −7.7 ± 7.4 kg; d = 1.05) and did not achieve statistical equivalence. Estimates using corrected V_{1RM} more closely matched measured 1-RM (mean difference = −0.4 ± 6.8 kg; d = 0.06) and demonstrated statistical equivalence, with the 90% confidence interval contained within predefined equivalence bounds (±7.2 kg).

Conclusion: Although 1-RM estimates derived from the corrected V_{1RM} showed minimal average bias, interindividual variability persisted across both estimation methods, limiting the accuracy of 1-RM predictions at the individual level.

1. Introduction

Decreased lower-limb muscle strength and power are key predictors of age-related declines in functional ability (Reid and Fielding, 2012). Resistance exercise remains the primary intervention to mitigate this deterioration (Currier et al., 2026). In this context, training load is commonly prescribed based on maximal dynamic strength, often assessed by researchers and practitioners using the one-repetition maximum (1-RM) test (Grgic et al., 2020). The 1-RM test quantifies the maximum load an individual can lift for a single repetition while maintaining proper technique and a full range of motion (Grgic et al., 2020). Although valid and reliable in older adults (Infante et al., 2021), 1-RM testing is time-consuming and may induce muscle soreness (Grgic et al., 2020). This is of particular concern given that recovery from resistance exercise is delayed and prolonged in older adults (Li et al., 2024), with implications for exercise adherence and programming (Hayes et al., 2023). Submaximal methods, such as Rating of Perceived Exertion and Repetitions in Reserve, offer less demanding alternatives

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https://doi.org/10.1016/j.exger.2026.113174
Received 15 January 2026; Received in revised form 31 March 2026; Accepted 9 May 2026

for monitoring and guiding training intensity (Morishita et al., 2019). However, these approaches are inherently subjective and influenced by factors such as mood, fatigue, and training experience, potentially compromising their validity (Bok et al., 2022; Larsen et al., 2021).

An increasingly adopted alternative to direct 1-RM testing is the estimation of maximal strength through load-velocity (L-v) profiling (Marston et al., 2022). This approach is based on the well-established inverse relationship between concentric movement velocity and external load (González-Badillo and Sánchez-Medina, 2010), allowing regression-based models to predict 1-RM without the need for maximal lifting. Although the L-v relationship exhibits both linear and hyperbolic characteristics, linear models are generally accurate within the dynamic range of measurable loads (Alcazar et al., 2021).

Linear L-v profiling has been applied to estimate 1-RM across various lower-limb exercises and populations; however, only two studies have examined its use in the leg press exercise among older adults (Marques et al., 2021; Marcos-Pardo et al., 2019). In both studies, a single group-derived L-v equation was used to characterize the L-v relationship across all participants. While this method produced acceptable estimates of relative load, it inherently assumes homogeneity in the L-v relationship in older adult. Age-related declines in force and velocity capacities vary substantially between individuals, manifesting as impairments in force, velocity, both or neither (Alcazar et al., 2023). Generalized L-v equations overlook this interindividual variability and may obscure meaningful individual differences that compromise estimation accuracy. Consequently, individualized L-v profiling may represent a more valid and precise approach for estimating 1-RM in older populations.

An important consideration when using individualized L-v profiles to estimate 1-RM is the requirement to specify the velocity associated with 1-RM (V_{1RM}) as a model input. Notably, although the L-v relationship itself exhibits substantial interindividual variability (Alcazar et al., 2023), previous research has demonstrated the validity of applying a population mean V_{1RM} value for the leg press exercise (Díez-Fernández et al., 2023).

Adopting a mean V_{1RM} instead of individualized V_{1RM} values offers two key advantages. First, determining an individual's V_{1RM} would necessitate performing a true 1-RM test, directly undermining the primary rationale of L-v profiling, which is to avoid maximal loading. Second, while velocity measurements are highly reliable at submaximal loads, reliability markedly deteriorates at 1-RM intensities (Banyard et al., 2018), limiting the usefulness of individual V_{1RM} values. Collectively, these considerations suggest that combining individualized L-v equations with a mean V_{1RM} constitutes a pragmatic approach for estimating 1-RM in older adults.

However, despite the practical value of a mean V_{1RM}, defining an appropriate value remains challenging. The use of V_{1RM} as an input in individualized L-v equations relies on the assumption that the 1-RM point lies directly on the regression line derived from submaximal loads. In practice, while the L-v relationship is approximately linear across moderate loads, it becomes nonlinear and concave as maximal loads are approached, causing the true 1-RM to fall to the left of the line extrapolated from submaximal data (Alcazar et al., 2019). As a result, using the population mean V_{1RM} as a standard input is likely to systematically overestimate true 1-RM values. In line with this observation, a recent systematic review reported a consistent tendency for L-v models to overpredict 1-RM and highlighted the need for improved approaches to defining V_{1RM} (Greig et al., 2023).

Although a hyperbolic model could be used to capture the nonlinearity of the L-v relationship at high loads, its practical application is considerably more complex than that of linear modeling. Notably, a recent study in young adults proposed an innovative strategy to address this nonlinearity when estimating 1-RM from the L-v profile in the back squat exercise (Thompson et al., 2021). Instead of relying on V_{1RM} as a direct input, the authors used the velocity corresponding to 80% of 1-RM to estimate the 80% load and subsequently extrapolated the regression to predict 100% 1-RM (Thompson et al., 2021). By circumventing the need to directly model V_{1RM}, this approach reduced prediction errors while retaining the simplicity of linear modeling. To date, however, no studies have investigated whether similar correction strategies can improve individualized L-v-based 1-RM estimations in older adults.

In response to the limited literature on individualized L-v profiling in older adults, the present study provides an evaluation of the validity of individualized L-v-based 1-RM estimation in this population. Moreover, it tests whether incorporating a corrective strategy that addresses the nonlinear behavior of the L-v relationship at high loads can attenuate the systematic overestimation of 1-RM and substantially improve the precision of individualized strength predictions.

2. Methods

2.1. Participants

Ninety-six community-dwelling adults (60 males, 36 females) aged 55 to 81 years old participated in the study. Exclusion criteria included unstable cardiovascular disease, neurological disorders, inability to comprehend test instructions, low physical function (short physical performance battery score (SPPB) < 7), acute infections or fever, and severe musculoskeletal conditions. All participants provided written informed consent prior to participation. Based on available self-reported IPAQ-SF (Craig et al., 2003) data, participants engaged in moderate-intensity activities a median of 2 days per week, vigorous activities 0 days per week and walking 4 days per week, with each activity performed for at least 10 min continuously to count toward a given day. Mean sedentary time was 6.7 ± 2.4 h per day. None had participated in structured resistance training during the previous 12 months. All were well-functioning, with the average total SPPB score of 11.5 ± 0.9. All participants provided written informed consent in accordance with the process approved by the Ethics Committee UZ/KU Leuven (S68434) and in accordance with the Declaration of Helsinki.

2.2. Design and procedures

A cross-sectional design was used to assess the accuracy of the 1-RM estimation methods on a leg press device. All participants completed two testing sessions, separated by at least 48 h: a familiarization session and a main testing session.

2.2.1. Test protocol

Prior to the test, participants completed a standardized warm-up consisting of five minutes of cycling on a cycle ergometer at self-selected resistance, followed by two sets of unilateral leg extensions on the leg press test device: 10 repetitions at 15% and 6 repetitions at 30% of body mass, with the final 2–3 repetitions performed with maximal effort (i.e., as fast as possible).

All testing was conducted on a Keiser A400 horizontal pneumatic leg press (Keiser Sport, Fresno, USA) using the participant's dominant leg. Movement velocity was calculated by the system's built-in software from piston displacement within the air cylinder (Larsen et al., 2023). The seat position was individually adjusted to achieve a knee angle of 90°, with the heel placed at the lower edge of the footplate. The non-dominant leg remained relaxed, with the foot positioned on the movable stop beneath the footplate. A single-leg protocol was used instead of a bilateral protocol to more closely replicate functional demands of daily activities, such as walking and stair climbing. Throughout testing, participants were instructed to hold the side handles to ensure stabilization.

During the familiarization session, participants performed single, explosive concentric leg press repetitions across five submaximal loads. Since maximal strength had not yet been assessed, loads were prescribed relative to body mass (Alcazar et al., 2017). Specifically, participants executed extensions at 12.5%, 25%, 37.5%, 50% and 62.5% of their body mass, providing a broad range of submaximal intensities to facilitate reliable load-velocity profiling (Banyard et al., 2017). Three trials were completed for the first three loads, and two trials for the final two. For each load, the trial with the highest mean concentric velocity was retained. These load-velocity data points were used to estimate each participant's estimated maximal isometric load (L₀) using linear regression.

In the main testing session, participants again performed single explosive concentric leg extensions, this time using five submaximal loads relative to their estimated L₀ from the familiarization session (7.5%, 15%, 30%, 45% and 60%). Three trials were completed at the three lightest loads, and two trials at the two heavier loads. After completing these submaximal sets, participants performed additional single-repetition trials with progressively increasing loads until their 1-RM was reached. Rest intervals ranged from 60 s to 120 s and were adjusted according to the load of the preceding trial (Alcazar et al., 2017): 60 s for the three lightest loads, 90 s for the two heavier loads and 120 s for the additional repetitions up 1-RM.

2.2.2. L-v profiling

L-v profiles were generated for each participant using a validated protocol (Alcazar et al., 2017). For each of the five submaximal loads, the trial with the highest mean concentric velocity was selected, and a linear regression was applied to these data. To ensure data quality, outliers were excluded if they fell more than 0.03 $m \cdot s^{-1}$ below the predicted regression line. On average, 4.3 ± 0.6 data points were retained per participant. All individual regression models demonstrated excellent linearity, with coefficients of determination (R^2) of at least 0.98.

From each regression, the following variables were obtained: estimated isometric maximal load (L₀), estimated maximal unloaded velocity (V₀), slope of L-v relationship (S_{LV}; the proportional decrease in velocity with increasing load) and maximal power output (P_{max}), calculated as (L₀·V₀)/4.

Test-retest reliability was evaluated in 28 participants (14 males, 14 females). P_{max} ($W \cdot kg^{-1}$), L_0 ($N \cdot kg^{-1}$) and V_0 ($m \cdot s^{-1}$) showed excellent consistency, with Intraclass Correlations Coefficients (two-way mixed, absolute agreement, single measures) of 0.99, 0.99 and 0.92, and within-subject coefficients of variation of 2.4 ± 1.8%, 2.5 ± 1.8% and 2.1 ± 1.4%, respectively.

2.2.3. Estimating 1-RM

Fig. 1 presents a visual overview of the method employed to estimate 1-RM. To estimate each participant's 1-RM load, their individualized linear L-v regression equation was applied:

$$1RM = (S_{LV} \bullet V_{1RM}) + L_0$$

The variables S_{LV} and L_0 were extracted directly from each participant's L-v profile and varied between individuals. In contrast, V_{1RM} was not individualized. Instead, sex-specific group averages were used.

Sex-specific averages for V_{1RM} were determined using two distinct methods. The first method involved directly measuring each participant's 1-RM and calculating the group mean, referred to as the 'measured V_{1RM}', which was 0.17 ± 0.08 $m \cdot s^{-1}$ for males and 0.18 ± 0.09 $m \cdot s^{-1}$ for females. The second method accounted for the non-linear (concave) nature of the L-v relationship at high loads, which can cause overestimation when extrapolating from submaximal data. For this approach, each participant's measured 1-RM was input into their individual L-v regression to calculate the corresponding velocity. The

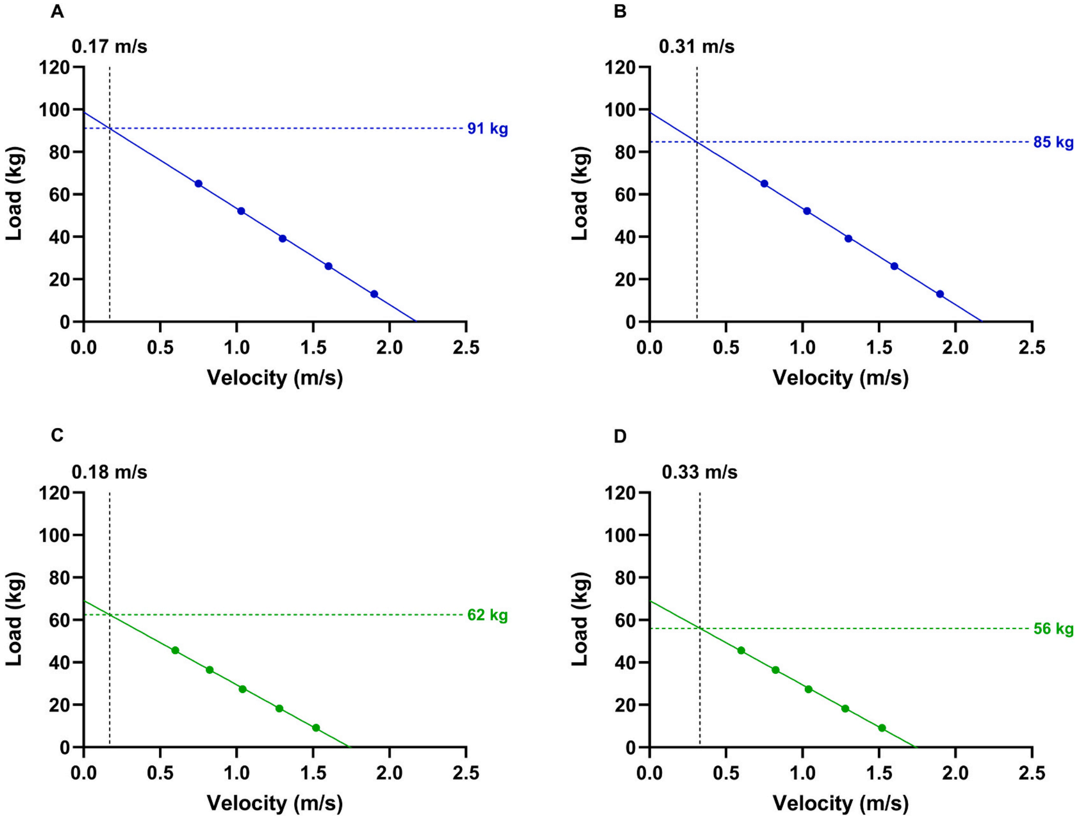

Fig. 1. Graphical illustration of the two 1-RM estimation methods. Each panel displays the 5-point load-velocity profile of a hypothetical male (A and B, blue) and female (C and D, green) participant. 1-RM was estimated by solving each participant's individualized L-v regression at a sex-specific group average V_{1RM}. Two V_{1RM} values were derived per sex: a measured V_{1RM} (A and C), defined as the mean velocity observed at participants' directly measured 1-RM (males: 0.17 ± 0.08; females: 0.18 ± 0.09 $m \cdot s^{-1}$), and a corrected V_{1RM} (B and D), adjusted to account for the overestimation of 1-RM velocity that occurs when a linear regression is extrapolated across a concave L-v relationship (males: 0.31 ± 0.15; females: 0.33 ± 0.12 $m \cdot s^{-1}$). Each V_{1RM} was then substituted into participants' individual L-v equations to yield two independent 1-RM estimates. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

individual velocities were then averaged to yield a 'corrected V_{1RM}' of 0.31 ± 0.15 m·s^{-1} for males and 0.33 ± 0.12 m·s^{-1} for females. Both the measured and corrected V_{1RM} values were subsequently used in each participant's L-v equation to produce two separate 1-RM estimates. Importantly, all V_{1RM} and 1-RM estimates were derived from the same individual L-v profiles using an identical number of data points, thereby avoiding bias due to differences in data inclusion.

2.3. *Statistical analysis*

Statistical analyses were performed using RStudio (Version 2025.05.1 Build 513; Posit Software, PBC). All analyses were conducted separately for each 1-RM estimation method. Paired differences were calculated as measured 1-RM minus estimated 1-RM. Normality of the paired differences was assessed using the Shapiro-Wilk test. Effect sizes for the differences between measured and estimated 1-RM values were quantified using Cohen's d and interpreted as trivial (<0.20), small (0.20–0.50), medium (0.51–0.80), or large (>0.80) (Cohen, 1992; Van Roie et al., 2025).

Statistical inference was based on equivalence testing using the Two One-Sided Tests (TOST) procedure for paired samples. Equivalence bounds were set at ±3.6 kg, corresponding to ±5% of the mean measured 1-RM of the sample, and representing a conservative threshold relative to previously reported test-retest variability (~10%) of the Keiser pneumatic leg press in older women (Infante et al., 2021). Equivalence was concluded when both one-sided tests were significant at $\alpha = 0.05$, corresponding to the 90% confidence interval of the mean difference lying entirely within the equivalence bounds. No a priori power analysis was conducted as the sample was embedded within a larger study. However, if the estimation method demonstrated equivalence, a sensitivity analysis was performed and achieved power was reported. If the estimation method failed equivalence, the sensitivity analysis was not applicable, as the detection of significant systematic bias itself confirmed adequate sample sensitivity.

Agreement between measured and estimated 1-RM values was further examined using Bland-Altman analyses. Bland-Altman plots illustrated mean differences, a regression line of the difference on the mean of the two methods to assess proportional bias, and 95% limits of agreement (LoA) to capture the range of individual disagreement between methods. Differences were expressed in both absolute terms and as a percentage of the measured 1-RM. Agreement was further quantified using the intraclass correlation coefficient (ICC) for absolute agreement, derived from a two-way mixed-effects model and interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), or excellent (>0.90)) (Koo and Li, 2016), and by linear regression reporting the coefficient of determination (R^2) and standard error of the estimate (SEE). Statistical significance was set at $p < 0.05$.

Table 1
Means ± SD for participant characteristics and L-v profile parameters.

	Both ($n = 96$)	Male ($n = 60$)	Female ($n = 36$)
Age (years)	69 ± 5.8	70 ± 5.6	69 ± 6
Body height (m)	1.72 ± 0.09	1.76 ± 0.07	1.65 ± 0.07
Body mass (kg)	75.3 ± 12.7	79.4 ± 11.4	68.4 ± 11.9
BMI (kg·m^{-2})	25.4 ± 3.6	25.5 ± 3.0	25.3 ± 4.4
L-v profile parameters			
L_0 (kg)	88.5 ± 23.7	100.1 ± 19.9	69.2 ± 15.4
V_0 (m·s^{-1})	1.74 ± 0.28	1.83 ± 0.30	1.59 ± 0.15
S_{LV} (kg·s·m^{-1})	−50.4 ± 11.8	−54.2 ± 10.9	−43.9 ± 10.5
P_{max} (W)	386.8 ± 131.5	457.4 ± 108.7	269.3 ± 65.6

Abbreviations: BMI = body mass index; L-v = load-velocity; L_0 = estimated maximal isometric load; V_0 = estimated maximal unloaded velocity; S_{LV} = slope of the L-v relationship; P_{max} = maximal muscle power.

3. Results

Table 1 summarizes participant characteristics and L-v profile parameters for the total sample and separated by sex.

Table 2 shows the measured 1-RM, estimated 1-RM based on measured V_{1RM} and estimated 1-RM based on corrected V_{1RM} for the total sample and separated by sex.

Fig. 2 presents the results of the TOST equivalence analysis. The estimated 1-RM derived from the measured V_{1RM} differed substantially from the measured 1-RM (mean difference = −7.7 ± 7.4 kg; $d = 1.05$), reflecting a large systematic underestimation. Statistical equivalence was not demonstrated, as the 90% CI (−9.0 to −6.5 kg) fell entirely outside the predefined equivalence bounds of ±3.6 kg, and only one of the two one-sided tests was significant ($p_1 = 1.000$, $p_2 < 0.001$). In contrast, the estimated 1-RM derived from the corrected V_{1RM} showed negligible deviation from the measured 1-RM (mean difference = −0.4 ± 6.8 kg; $d = 0.06$). Statistical equivalence was established, as the 90% CI (−1.6 to 0.7 kg) lay entirely within the predefined equivalence bounds, and both one-sided tests reached statistical significance ($p_1 < 0.001$, $p_2 < 0.001$). A sensitivity analysis for the corrected V_{1RM} method indicated 99.8% achieved power ($n = 96$, SD = 6.8 kg), confirming that the sample was more than adequate to detect equivalence. For the measured V_{1RM} method, a sensitivity analysis was not warranted, as the large and significant systematic bias ($d = 1.05$, $p < 0.001$) itself demonstrates sufficient sample sensitivity to detect meaningful disagreement.

Fig. 3A and B show Bland-Altman plots of absolute and relative differences between measured 1-RM and 1-RM estimated from the measured V_{1RM}. The 95% LOA ranged from −22.2 to 6.8 kg for absolute differences and from −32.5% to 9.1% for relative differences. Absolute differences showed no evidence of proportional bias, as indicated by the absence of a significant association between the differences and the mean of the two methods ($r = 0.068$, $p = 0.51$). In contrast, relative differences exhibited significant proportional bias ($r = 0.30$, $p < 0.05$), with negative bias decreasing as 1-RM values increased.

Fig. 3C and D show Bland-Altman plots for 1-RM estimates derived from the corrected V_{1RM}. The 95% LOA were narrower (−13.7 to 12.9 kg for absolute differences and − 19.3% to 17.1% for relative differences). Absolute differences showed evidence of proportional bias ($r = 0.24$, $p < 0.05$), whereas relative differences showed a non-significant trend toward proportional bias ($r = 0.20$, $p = 0.06$). As in the measured V_{1RM} estimation method, negative bias decreased with increasing 1-RM values, with the regression line crossing zero near the midpoint of the 1-RM range.

Fig. 4A and B present linear regression plots of measured versus estimated 1-RM values derived from the measured V_{1RM} and corrected V_{1RM} methods, respectively. Using the measured V_{1RM}, the estimated 1-RM accounted for a substantial proportion of variance in the measured 1-RM ($R^2 = 0.888$, $p < 0.001$); however, individual-level prediction remained limited (SEE = 7.4 kg). A comparable pattern emerged for the corrected V_{1RM}-based estimates, with a marginally higher coefficient of variation and improved precision ($R^2 = 0.898$, $p < 0.001$, SEE = 6.7 kg).

Table 2
Means ± SD for the measured and estimated 1-RM values.

	Both (n = 96)	Male (n = 60)	Female (n = 36)
Measured 1-RM (kg)	72.1 ± 21.2	82.9 ± 18.1	54.0 ± 11.6
Estimated 1-RM from measured V_{1RM} (kg)	79.8 ± 22.0	91.0 ± 18.2	61.3 ± 13.7
Estimated 1-RM from corrected V_{1RM} (kg)	**72.5 ± 20.7**	**83.2 ± 16.9**	**54.6 ± 12.3**

Bold numbers indicate that estimates were statistically equivalent to the measured 1-RM, based on the Two One-Sided Tests (TOST) procedure with equivalence bounds of ±5% of the measured 1-RM. Abbreviations: 1-RM = one-repetition maximum; V_{1RM} = velocity at 1-RM.

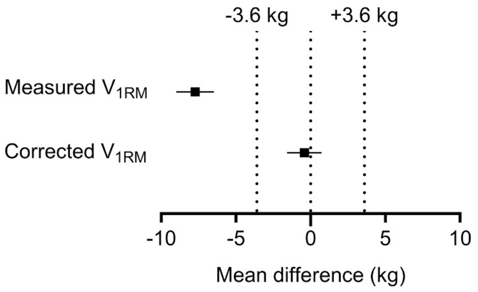

Fig. 2. Equivalence testing of measured 1-RM and 1-RM values estimated using the measured V_{1RM} and corrected V_{1RM} methods. Square points represent mean differences between measured and estimated 1-RM (kg) with 90% confidence intervals shown as error bars. Dashed lines indicate the predefined equivalence bounds of ±3.6 kg (±5% of mean measured 1-RM). The measured V_{1RM} method exceeded the equivalence bounds (mean difference = −7.7 kg, 90% CI: −9.0 to −6.5 kg), indicating non-equivalence. The corrected V_{1RM} method fell within the equivalence bounds (mean difference = −0.4 kg, 90% CI: −1.6 to 0.7 kg), indicating statistical equivalence.

Absolute agreement was good for the measured V_{1RM} method (ICC = 0.89, $p < 0.001$) and excellent for the corrected V_{1RM} method (ICC = 0.95, $p < 0.001$).

4. Discussion

This study examined the validity of a novel approach for estimating 1-RM in men and women aged 55 years and older using a pneumatic leg press. The method combined individualized load-velocity regression equations derived from submaximal measurements with either a sex-specific mean measured V_{1RM} or a mean corrected V_{1RM}. The corrected V_{1RM} method outperformed the measured V_{1R}M method across all agreement indices: mean bias was trivial (−0.4 kg vs. −7.7 kg), absolute agreement was excellent vs. good (ICC = 0.95 vs. 0.89), and only the corrected method achieved statistical equivalence with the measured 1-RM. Nevertheless, considerable interindividual variability persisted across both methods (SEE = 6.7 vs. 7.4 kg), indicating that even the corrected approach does not provide accurate estimation at the individual level.

Two previous studies developed L-v equations to estimate relative load (%1-RM) during leg press exercise in older adults based on movement velocity (Marques et al., 2021; Marcos-Pardo et al., 2019). However, these approaches relied on generalized L-v equations and still

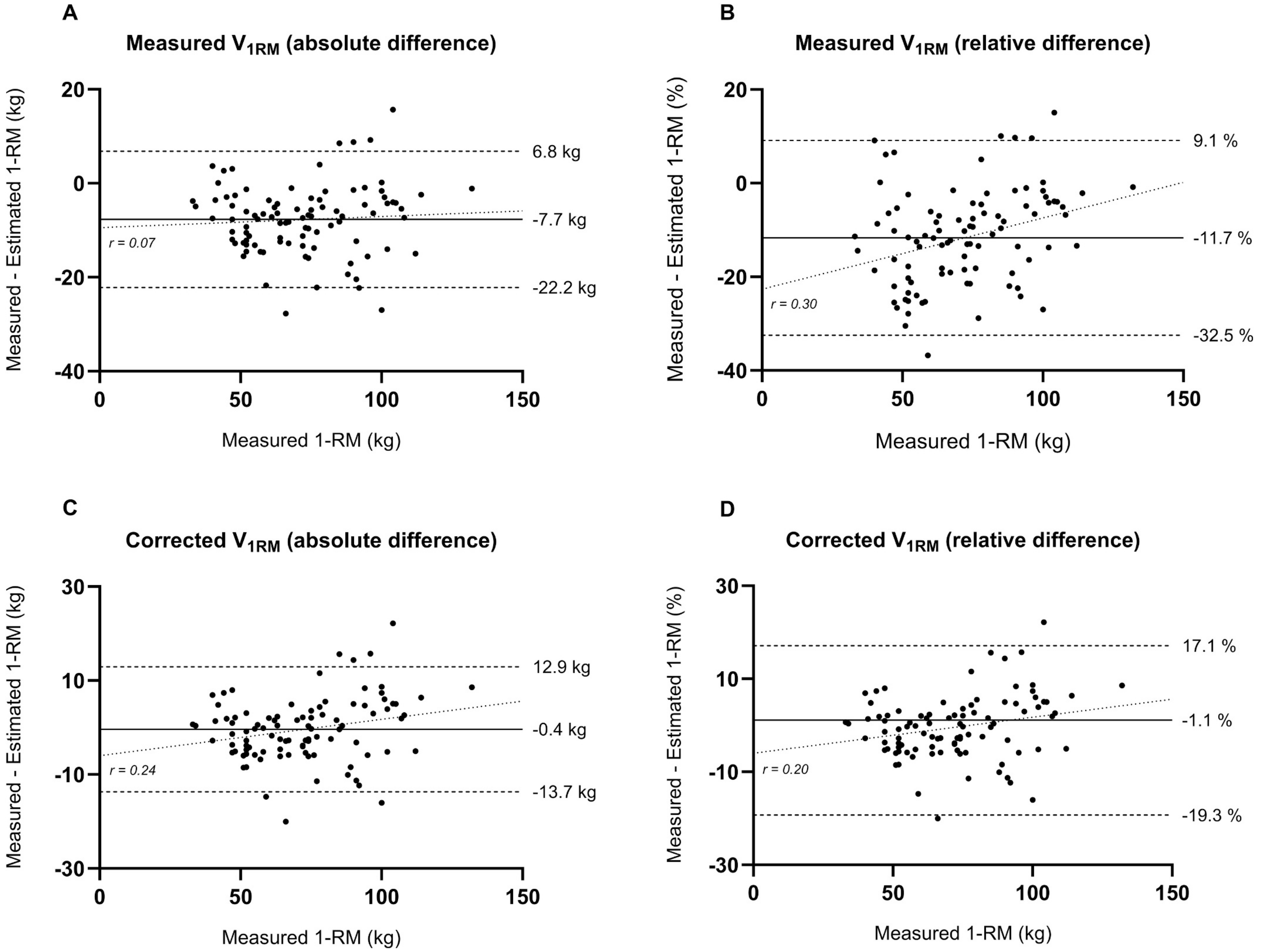

Fig. 3. Bland-Altman plots of absolute and relative differences between measured 1-RM and 1-RM values estimated using the measured V_{1RM} and corrected V_{1RM} methods. Panels A and B show the absolute and relative differences between the measured 1-RM and the 1-RM estimated from the measured velocity at 1-RM (measured V_{1RM}). Panels C and D show the absolute and relative differences between the measured 1-RM and the 1-RM estimated from the corrected velocity at 1-RM (corrected V_{1RM}). *X*-axis: measured 1-RM (kg); *Y*-axis: absolute difference (measured – estimated 1-RM, kg) or relative difference ((measured – estimated 1-RM) / measured 1-RM, %). Solid line = systematic bias; dotted line = proportional bias; dashed lines = limits of agreement (95% CI).

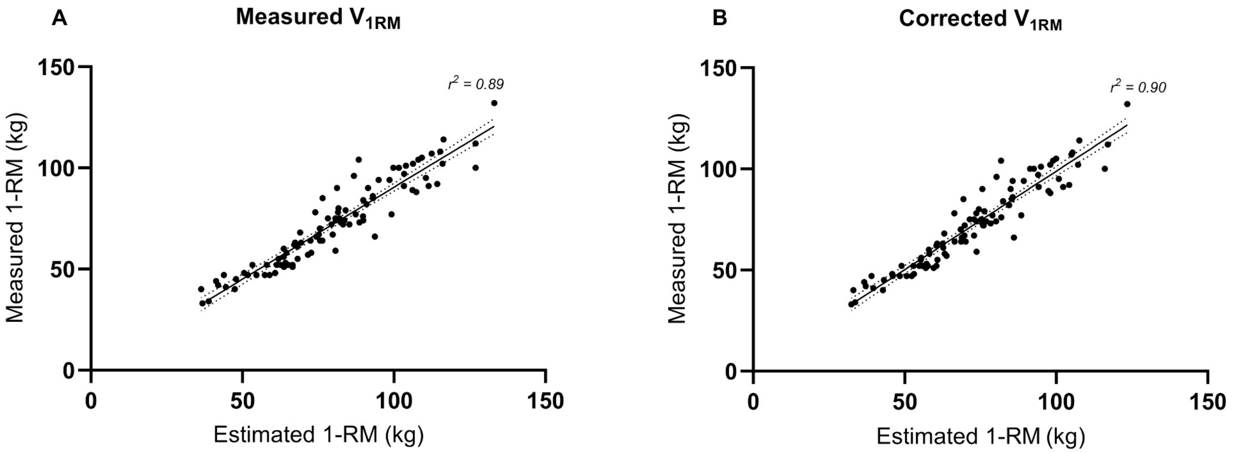

Fig. 4. Linear regression plots of measured 1-RM versus 1-RM values estimated using the measured V_{1RM} and corrected V_{1RM} methods. Panel A shows the linear relationship between the measured and estimated 1-RM from the measured V_{1RM} ($Y = 0.99\times + 9.44$). Panel B shows the linear relationship between the measured and estimated 1-RM from the corrected V_{1RM} ($Y = 0.92\times + 5.99$). *X*-axis: measured 1-RM (kg); *Y*-axis: estimated 1-RM (kg); r^2 = coefficient of determination; dotted lines = limits of agreement (95% CI).

required individual measurements of V_{1RM} to predict 1-RM. In contrast, the present approach combines individualized L-v equations derived from submaximal data with a population mean V_{1RM}, with the objective of eliminating the need for maximal-effort testing. This fundamental methodological difference limits the direct comparability of our findings with studies based on generalized L-v models.

Studies that did investigate individualized, rather than generalized, L-v equations to predict 1-RM – although not specifically in older adults – have consistently reported systematic overestimations. These inaccuracies are commonly attributed to the concave shape of the L-v relationship at higher loads, which shifts the true 1-RM to the left of the linear regression derived from submaximal loads (Alcazar et al., 2019). For instance, Ruf et al. (Ruf et al., 2018) and Banyard et al. (Banyard et al., 2017) reported substantial overestimations of 1-RM in the deadlift and back squat when individualized L-v equations incorporated the measured V_{1RM}. Similarly, in a leg press study involving female breast cancer survivors, the application of mean measured V_{1RM} resulted in overestimated 1-RM values (Díez-Fernández et al., 2023).

Several strategies have been proposed to mitigate overestimation of 1-RM from L-v equations. Thompson et al. (2021) suggested using the L-v relationship to estimate 80% of 1-RM from an established reference velocity at 80% of 1-RM and then extrapolating to predict 1-RM. By avoiding direct estimation of 1-RM using V_{1RM}, this approach reduced prediction error. Building on these findings, the present study evaluated whether circumventing the use of a measured V_{1RM} and instead applying a corrected V_{1RM} could account for systematic overestimation and improve 1-RM prediction accuracy. The results confirmed that this correction effectively reduced bias.

Despite improvements in group-level estimation accuracy when using the corrected V_{1RM}, substantial interindividual variability in 1-RM predictions remained for both 1-RM estimation approaches. This is evident from the wide limits of agreement (−22.2 to 6.8 kg for the measured V_{1RM} and − 13.7 to 12.9 kg for the corrected V_{1RM} approach). These observations are consistent with Kurobe & Momose (Kurobe and Momose, 2023), who used individualized L-v equations to determine F_0 and leveraged the strong correlation ($r = 0.88$) between F_0 and measured 1-RM to estimate 1-RM in healthy young females on the leg press. While their approach showed high group-level accuracy, notable interindividual differences persisted, with regressions between the measured and estimated values showing an SEE of 14.4% (12.5 kg) relative to the average 1-RM (87 kg). Similarly, Larsen et al. (Larsen et al., 2023) evaluated various lower-limb strength tests for 1-RM estimation in recreationally active young adults and found that the individualized L-v approach was the most valid at the group level. However, they also reported considerable interindividual variation, with a SEE of 6.8% (20.4 kg) relative to a 1-RM of 300 kg. These findings align closely with our observed variability, reinforcing the conclusion that individualized L-v approaches improve group-level predictions but remain limited in their reliability for individual 1-RM estimation.

In our study, variability in estimation errors likely reflected differences in how each participant's corrected V_{1RM} deviated from the group mean. We used a mean V_{1RM} instead of individualized values because obtaining corrected individual V_{1RM} would require participants to perform a true 1-RM test, which contradicts the purpose of the L-v method for estimating 1-RM without maximal effort. Although previous research supports the validity of using a mean V_{1RM} (Díez-Fernández et al., 2023), our exploratory analysis revealed a strong association between estimation error and individual deviation from the mean ($r = 0.971$, $p < 0.001$). Participants whose corrected V_{1RM} differed more from the mean experienced larger errors, suggesting that a generalized V_{1RM} may be insufficient for accurate individual predictions. Given that age can influence the L-v relationship (Alcazar et al., 2023), we explored whether narrowing the age range would reduce variability. This was not the case: among participants aged 60+ and 65+, the mean and standard deviation of V_{1RM} were nearly identical to those of the full sample aged 55+ (means: 0.17–0.18 m/s; SD: 0.08–0.09 m/s).

Beyond variability, the generalizability of V_{1RM} values warrants consideration. Our findings apply specifically to healthy, untrained adults aged 55 and older. Age is a relevant factor, as older adults produce lower mean concentric velocities at submaximal loads than younger adults (Tøien et al., 2022), reflecting a downward shift of the load-velocity relationship that is most pronounced at lower loads (Alcazar et al., 2023) and may be even more pronounced in the presence of frailty, given the greater neuromuscular deficits observed in this population. Whether these changes extend to V_{1RM} is less clear: since the velocity decline attenuates as load increases, age-related differences may be relatively small at the extreme high-load end of the continuum where V_{1RM} is measured. Consistent with this, one study reported comparable V_{1RM} values between older and younger women (Marcos-Pardo et al., 2019), though the evidence base is too limited to draw firm conclusions, and direct empirical investigation across age groups is warranted. Training status is equally relevant, and whether the V_{1RM} values reported here generalize to resistance-trained older adults has yet to be examined.

Along with individual characteristics, the equipment and exercise used should also be considered. In the current study, a pneumatic leg press was selected because it allows higher velocities at lighter loads than weight-stack devices (Peltonen et al., 2013), thereby expanding the load-velocity range and improving measurement reliability (Banyard et al., 2017). Pneumatic resistance also attenuates the high inertial forces of mass-based exercise, reducing musculoskeletal strain and potentially lowering injury risk in older adults (Larsen et al., 2023). However, since V_{1RM} values were obtained exclusively on this device, their generalizability to other resistance equipment remains unknown, and replication across different machine types is necessary before these findings can be broadly applied in clinical or gym-based settings. The specific exercise performed adds a further layer of complexity: bilateral and unilateral load-velocity profiles differ meaningfully in regression intercepts and velocity at each percentage of 1-RM (Balsalobre-Fernández et al., 2019), and age-related neuromuscular changes (Alcazar et al., 2023) may amplify this discrepancy in older adults. We therefore advise against applying unilateral-derived V_{1RM} values to bilateral 1-RM estimation until this is further investigated.

Given the observed variability in V_{1RM}-based estimation, alternative approaches that do not rely on V_{1RM} may offer greater prediction accuracy. One promising method uses an individual's load-velocity profile to estimate the load intercept (L_0) and predict 1-RM from the relationship between L_0 and measured 1-RM. An analogous approach using the force-velocity profile has been reported (Kurobe and Momose, 2023), where the force intercept (F_0) predicted 1-RM via the eq. 1-RM = 0.08 × F_0–3.00, yielding a strong correlation with measured 1-RM (r = 0.88, 95% CI: 0.55–0.97, $p < 0.05$). F_0 and L_0 reflect the same theoretical construct (i.e., the extrapolated maximum load or force at zero velocity) differing only in their units and measurement requirements: F_0 is expressed in Newtons and requires direct force measurement, whereas L_0 is expressed in kilograms and is therefore more practical in applied and clinical settings. Despite the strong F_0 to 1-RM correlation, the R^2 of 0.77 indicates that prediction accuracy was moderate, leaving room for improvement. A further alternative is to bypass 1-RM estimation entirely and prescribe training loads directly relative to L_0 or F_0 (Baltasar-Fernandez et al., 2024). This approach avoids the risks of maximal testing and accommodates interindividual variability in L-v profile without relying on accurate estimations of 1-RM. Future research should evaluate whether these F_0-based approaches offer greater accuracy than V_{1RM}-based methods and examine their applicability across different populations, devices and exercise modalities.

A final consideration concerns the methodological variation across studies in how L-v profiles are constructed, with differences in the number of submaximal loads, the velocity metric (mean vs. peak), and the modeling approach (linear vs. quadratic). Five loads were used in the present study because, although comparable validity has been reported for 2- and 3-load protocols (Ruf et al., 2018), a greater number of loads may improve the reliability of 1-RM predictions (Banyard et al., 2017). Mean velocity was selected as the velocity metric, which on the pneumatic leg press corresponds to mean propulsive velocity given that resistance is largely independent of inertia, eliminating the need to decelerate large masses; prior research indicates this metric yields more accurate 1-RM estimates than overall mean velocity or peak velocity (Conceição et al., 2016). A linear model was preferred over quadratic or hyperbolic alternatives because, although the L-v relationship exhibits hyperbolic characteristics at extreme loads, linear models perform well within the range of loads typically used in practice (Alcazar et al., 2021), and the superiority of more complex models has been reported as small and of limited practical relevance (Greig et al., 2023). Non-linearity at higher loads was instead addressed through an empirical V_{1RM} correction. This accounts for the overestimation inherent in extrapolating a linear fit into the concave region of the L-v curve at high loads, without resorting to more complex modeling that may be difficult to implement in applied settings.

5. Conclusion

Overall, 1-RM estimates derived from the corrected V_{1RM} showed minimal average bias and were statistically equivalent, while this was not the case when estimates were derived from measured V_{1RM}. However, interindividual variability persisted across both estimation methods, limiting the accuracy of 1-RM predictions at the individual level. In community-based or fitness-center programs for older adults, where individualized L-v profiling is rarely feasible, group-level analyses appear sufficient and practically valuable for evaluating program outcomes and informing general exercise prescription. However, in contexts emphasizing individualized performance monitoring, this approach may not be appropriate due to limited individual-level precision. Therefore, consistent with a recent review (Greig et al., 2023), practitioners are encouraged to directly assess 1-RM whenever feasible to ensure accurate estimation of maximal strength.

CRediT authorship contribution statement

Jolien Deboutte: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Julian Alcazar:** Writing – review & editing, Methodology, Investigation. **Max Riesbeck:** Writing – review & editing, Methodology. **Simon Walker:** Writing – review & editing, Methodology. **Christophe Delecluse:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Evelien Van Roie:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Confirmation of ethical compliance

The study was approved by the Ethics Committee Research UZ/KU Leuven (S68434) in accordance with the Declaration of Helsinki.

Funding information

This work was supported by the internal research fund KU Leuven (C2M23033). J. Deboutte was supported by a doctoral fellowship from the Research Foundation – Flanders (1148025N). M. Riesbeck was supported by the Special Research Fund of Hasselt University (BOF25OWB22). J. Alcazar was supported by the Biomedical Research Networking Center on Frailty and Healthy Aging (CIBERFES; CB16/10/00477), the Plan Propio de Investigación of the University of Castilla-La Mancha, FEDER funds from the European Union (2022-GRIN-34296), and the Instituto de Investigación Sanitaria de Castilla-La Mancha (IDISCAM; TEC2022-007).

Declaration of competing interest

The authors have no competing interests to declare.

Acknowledgements

The authors thank Dr. Van Puyenbroeck for his assistance in the statistical analyses.

Data availability

Data will be made available on request.

References

Alcazar, J., et al., 2017. The force-velocity relationship in older people: reliability and validity of a systematic procedure. Int. J. Sports Med. 38 (14), 1097–1104.

Alcazar, J., et al., 2019. On the shape of the force-velocity relationship in skeletal muscles: the linear, the hyperbolic, and the double-hyperbolic. Front. Physiol. 10, 769.

Alcazar, J., et al., 2021. Comparison of linear, hyperbolic and double-hyperbolic models to assess the force-velocity relationship in multi-joint exercises. Eur. J. Sport Sci. 21 (3), 359–369.

Alcazar, J., et al., 2023. Ten-year longitudinal changes in muscle power, force, and velocity in young, middle-aged, and older adults. J. Cachexia. Sarcopenia Muscle 14 (2), 1019–1032.

Balsalobre-Fernández, C., Cardiel-García, M., Jiménez, S.L., 2019. Bilateral and unilateral load-velocity profiling in a machine-based, single-joint, lower body exercise. PLoS One 14 (9), e0222632.

Baltasar-Fernandez, I., et al., 2024. Power-oriented resistance training combined with high-intensity interval training in pre-frail and frail older people: comparison between traditional and cluster training set configurations on the force-velocity relationship, physical function and frailty. Eur. J. Appl. Physiol. 124 (2), 623–632.

Banyard, H.G., Nosaka, K., Haff, G.G., 2017. Reliability and validity of the load-velocity relationship to predict the 1RM back squat. J. Strength Cond. Res. 31 (7), 1897–1904.

Banyard, H.G., et al., 2018. The reliability of individualized load-velocity profiles. Int. J. Sports Physiol. Perform. 13 (6), 763–769.

Bok, D., Rakovac, M., Foster, C., 2022. An examination and critique of subjective methods to determine exercise intensity: the Talk Test, Feeling Scale, and Rating of Perceived Exertion. Sports Med. 52 (9), 2085–2109.

Cohen, J., 1992. A power primer. Psychol. Bull. 112 (1), 155–159.

Conceição, F., et al., 2016. Movement velocity as a measure of exercise intensity in three lower limb exercises. J. Sports Sci. 34 (12), 1099–1106.

Craig, C.L., et al., 2003. International physical activity questionnaire: 12-country reliability and validity. Med. Sci. Sports Exerc. 35 (8), 1381–1395.

Currier, B.S., et al., 2026. American College of Sports Medicine Position Stand. Resistance training prescription for muscle function, hypertrophy, and physical performance in healthy adults: an overview of reviews. Med. Sci. Sports Exerc. 58 (4), 851–872.

Díez-Fernández, D.M., et al., 2023. Estimating the one-repetition maximum on the leg-press exercise in female breast cancer survivors. PeerJ 11, e16175.

González-Badillo, J.J., Sánchez-Medina, L., 2010. Movement velocity as a measure of loading intensity in resistance training. Int. J. Sports Med. 31 (5), 347–352.

Greig, L., et al., 2023. The predictive validity of individualised load-velocity relationships for predicting 1RM: a systematic review and individual participant data meta-analysis. Sports Med. 53 (9), 1693–1708.

Grgic, J., et al., 2020. Test-retest reliability of the one-repetition maximum (1RM) strength assessment: a systematic review. Sports Med. Open 6 (1), 1–16.

Hayes, E.J., et al., 2023. Recovery from resistance exercise in older adults: a systematic scoping review. Sports Med. 9 (1), 51.

Infante, M.A., et al., 2021. One repetition maximum test-retest reliability and safety using Keiser pneumatic resistance training machines with older women. J. Strength Cond. Res. 35 (12), 3513–3517.

Koo, T.K., Li, M.Y., 2016. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J. Chiropr. Med. 15 (2), 155–163.

Kurobe, Y., Momose, K., 2023. Use of force-velocity relationship to estimate the one-repetition maximum leg press exercise among young females. J. Phys. Ther. Sci. 35 (3), 247–251.

Larsen, S., Kristiansen, E., van den Tillaar, R., 2021. Effects of subjective and objective autoregulation methods for intensity and volume on enhancing maximal strength during resistance-training interventions: a systematic review. PeerJ 9, e10663.

Larsen, F., et al., 2023. Reliability and validity of different lower-limb strength tests to determine 1RM in the Keiser A300 leg press. J. Strength Cond. Res. 37 (10), 1963–1968.

Li, D.C.W., et al., 2024. Age-associated differences in recovery from exercise-induced muscle damage. Cells 13 (3), 255.

Marcos-Pardo, P.J., et al., 2019. Movement velocity can be used to estimate the relative load during the bench press and leg press exercises in older women. PeerJ 7, e7533.

Marques, D.L., et al., 2021. Load-velocity relationship in the horizontal leg-press exercise in older women and men. Exp. Gerontol. 151, 111391.

Marston, K.J., et al., 2022. Load-velocity relationships and predicted maximal strength: a systematic review of the validity and reliability of current methods. PLoS One 17 (10), e0267937.

Morishita, S., et al., 2019. Rating of perceived exertion on resistance training in elderly subjects. Expert. Rev. Cardiovasc. Ther. 17 (2), 135–142.

Peltonen, H., Häkkinen, K., Avela, J., 2013. Neuromuscular responses to different resistance loading protocols using pneumatic and weight stack devices. J. Electromyogr. Kinesiol. 23 (1), 118–124.

Reid, K.F., Fielding, R.A., 2012. Skeletal muscle power: a critical determinant of physical functioning in older adults. Exerc. Sport Sci. Rev. 40 (1), 4–12.

Ruf, L., Chéry, C., Taylor, K.L., 2018. Validity and reliability of the load-velocity relationship to predict the one-repetition maximum in deadlift. J. Strength Cond. Res. 32 (3), 681–689.

Thompson, S.W., et al., 2021. A novel approach to 1RM prediction using the load-velocity profile: a comparison of models. Sports (Basel) 9 (7), 88.

Tøien, T., et al., 2022. Maximal intended velocity enhances strength training-induced neuromuscular stimulation in older adults. Eur. J. Appl. Physiol. 122 (12), 2627–2636.

Van Roie, E., van Uffelen, J., Delecluse, C., 2025. Stair-climbing versus machine-based resistance exercise to improve muscle power among older adults: a noninferiority trial. J. Strength Cond. Res. 39 (3), e496–e505.