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The Validity and Reliability of the Individual Load–Velocity Profiles in the Deadlift and Hip Thrust Exercises in Men and Women

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Abstract

Muscular strength assessment is fundamental for training optimization. While one-repetition maximum (1RM) testing is valid, its practical use is limited, making velocity-based training (VBT) a viable alternative for estimating maximal strength and monitoring performance using submaximal loads. This observational, cross-sectional validity and reliability study aimed to: (i) assess the absolute and relative reliability of movement velocity at submaximal loads in the deadlift and hip thrust, (ii) evaluate the validity and reliability of 1RM estimations using LVP in these exercises, and (iii) compare reliability metrics between sexes. Thirty-two physically active adults voluntarily participated in the study, including sixteen men (age: 25.63 ± 3.79 years; body mass: 75.79 ± 8.64 kg; height: 175.81 ± 7.34 cm) and sixteen women (age: 25.06 ± 5.37 years; body mass: 61.94 ± 4.25 kg; height: 165.06 ± 5.72 cm). Strength-trained participants performed familiarization and two experimental sessions involving progressive load tests at various percentages of 1RM. Movement velocity was monitored using a validated linear velocity transducer. Statistical analyses included two-way ANOVA, Bland–Altman plots and intraclass correlation coefficients (ICCs). The results showed a systematic overestimation of 1RM derived from load–velocity profiles, which was moderate for the deadlift (mean difference ≈ +2.7 kg; $p < 0.001$) and small-to-moderate for the hip thrust (≈+3.3 kg; $p = 0.002$). Strong associations were observed between actual and estimated 1RM in both exercises ($R^2 > 0.92$). Bland–Altman analyses revealed smaller bias but narrower limits of agreement for the deadlift compared with the hip thrust, indicating greater variability in hip thrust estimations. Test–retest analyses demonstrated good relative reliability of movement velocity in men across all loads (ICC > 0.75; CV < 8.2%), whereas women exhibited lower reliability, particularly at moderate-to-high loads in both exercises. Despite limited validity for precise 1RM estimation, load–velocity profiles showed good reproducibility, supporting their use for longitudinal performance monitoring rather than exact strength prediction.

Keywords: velocity-based training; one-repetition maximum; sex differences; strength monitoring; neuromuscular assessment

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1. Introduction

The assessment of muscular strength levels constitutes a critical component of the training process, providing essential insights into athletes' physical characteristics and the adaptations elicited through training regimens [1]. At the molecular level, strength training induces adaptations such as enhanced motor unit recruitment, increased firing frequency, improved neuromuscular synchronization, and upregulation of anabolic signaling pathways (e.g., mTOR), which collectively contribute to force production capacity. Morphologically, these adaptations are reflected in increases in muscle cross-sectional area, alterations in muscle architecture, and fiber-type-specific hypertrophy. Monitoring strength-related variables is therefore essential not only to quantify performance adaptations but also to guide training prescription, manage fatigue, and reduce injury risk in both health and sport contexts [2,3].

However, despite numerous studies addressing muscular strength assessment, several gaps remain in understanding the reliability and applicability of velocity-based monitoring across different exercises and sexes. Previous research, including studies by Ruf et al. (2018) [4], Çetin et al. (2022) [5], and the systematic review by Marston et al. (2022) [6], examined similar concepts primarily in squats or upper-body exercises, with limited and inconsistent integration into the context of deadlift and hip thrust assessments, despite the widespread use of these exercises in both athletic performance and rehabilitation programs. Therefore, strength and conditioning coaches need to evaluate athletes' muscular strength, design conditioning programs, examine individual training and health statuses [7], and inform about training readiness [8] to optimize training processes.

The main approach for evaluating dynamic muscular strength is the one-repetition maximum (1RM) test [1]. Direct 1RM assessment is a valid and reliable method [9] to determine maximal dynamic strength in several populations, but 1RM presents some disadvantages: (i) the assessment may yield inaccurate results for athletes with limited experience in the exercise, potentially leading to an underestimation of the real value of the 1RM, and the 1RM test could represent a risk of injury; (ii) the protocol necessitates multiple sets with submaximal weights, which can result in high time consumption and high fatigue when evaluating several athletes (e.g., team-sport squads) [10,11]. These limitations highlight the practical challenges of 1RM testing in applied settings, motivating the search for alternative, reliable methods for strength evaluation. For these reasons, monitoring 1RM presents practical limitations for tracking athletes' maximal dynamic strength. Additionally, 1RM can increase rapidly with training [12]; therefore, prescribing training intensity based on baseline 1RM may lead to a lower training intensity than that prescribed at the start of the training process.

As an alternative to direct 1RM assessment, supported by technological advances in linear velocity transducers and inertial measurement devices [13], velocity-based monitoring has become a simple, effective, and practical method for prescribing training intensity [14]. This method is based on the almost perfect inverse relationship between the load lifted and the concentric velocity at which the load is lifted [15]. While velocity-based methods have been extensively validated in exercises such as the bench press and squat, their validity and reliability in hip thrust and deadlift exercises remain less explored, particularly in female populations. Therefore, the individual load corresponding to a given movement velocity can be established simply by performing 3–5 progressive submaximal repetitions and applying a linear or polynomial regression model, resulting in the load–velocity profile (LVP) [13,15]. Thus, if the velocity associated with 1RM is known, the 1RM can be easily estimated. However, this relationship and the terminal velocity of the 1RM are exercise- and sex-specific, so this velocity presents inter-individual variability, which contributes to prediction error [14,16,17]. Loturco et al. [18] investigated the accuracy of predicting 1RM in the free-weight bench press and found an absolute difference of 5% between predicted and actual 1RM. In contrast, the actual 1RM in the free-weight back squat was significantly overestimated, with an absolute difference ranging from 20 to 30 kg [15]. Additionally, the estimated 1RM in the free-weight hip thrust exercise presented a standard error of the estimate between 7.01 and 7.36% [19]. Although the validity of LVP-derived 1RM estimations has been explored across several exercises, the reliability of individual LVPs—particularly across different loads and between sexes—has been investigated predominantly in the back squat and mainly in male samples [15]. As a result, the extent of inherent error associated with this methodology in other exercises and populations remains poorly understood.

This relationship between load and velocity is not only useful for estimating maximal dynamic strength values. Reductions in lifting movement velocity, compared to reference values with a fixed external load, are directly related to a limited capacity to produce muscular force. For example, after performing 30 repetitions of both the bench press and squat, the mean propulsive velocity decreased significantly in each exercise. This effect was observed by monitoring loads corresponding to 1 m/s and 75% of 1RM. Furthermore, the reduction in movement velocity relative to baseline values persisted for up to 48 h after the effort [20]. Given its sensitivity to exercise, monitoring the velocity of a lift can reveal the effects of fatigue during exercise [21] and the recovery process [22], as well as on the readiness to overcome a new training stimulus and to identify the potentiation effects after resistance exercise [23].

Given the broad application of velocity-based monitoring in applied settings, establishing the reliability and validity of the variables derived from individual load–velocity profiles is essential to ensure meaningful interpretation of performance changes. Understanding reliability across exercises and sexes will allow practitioners to implement velocity-based monitoring confidently, identify true performance changes, and optimize training prescriptions while minimizing error. Importantly, despite the widespread use of the deadlift and hip thrust for developing lower-body strength, the reliability and validity of individual LVPs in these exercises—especially in women—remain insufficiently characterized. Therefore, the aim of this study was to examine the validity and reliability of individual load–velocity profiles in the deadlift and hip thrust exercises in men and women. It was hypothesized that: (i) LVP-derived 1RM estimations would show systematic exercise-specific bias, (ii) movement velocity would demonstrate higher reliability in men than in women, particularly at higher loads, and (iii) reliability metrics would differ between the deadlift and hip thrust due to their distinct biomechanical and technical characteristics.

2. Materials and Methods

2.1. Design

This observational, cross-sectional test–retest validity and reliability study employed a repeated-measures design, in which participants completed three experimental sessions with a one-week interval between them (Figure 1). The first experimental sessions were employed as familiarization sessions to explain the protocol and the technique of the exercises. The subjects performed the 1RM test in the next two sessions. Following a standardized general warm-up, participants performed submaximal incremental sets based on mean propulsive velocity. Subsequently, participants attempted to lift the load corresponding to their previous 1RM, with increments of 2–5 kg added until they were unable to complete a successful lift, with 5 min of rest between attempts. The experimental sessions were conducted at the same place and time of day (±1 h) for each subject and under the same environmental conditions. These sessions involved performing an incremental load of the 1RM for both hip thrust and deadlift while mean propulsive velocity (MPV) was monitored. The exercise order (deadlift vs. hip thrust) was counterbalanced across sessions to minimize order effects. Participants were requested to avoid strenuous exercise and beverages containing caffeine/alcohol for 24 h prior to testing every testing session.

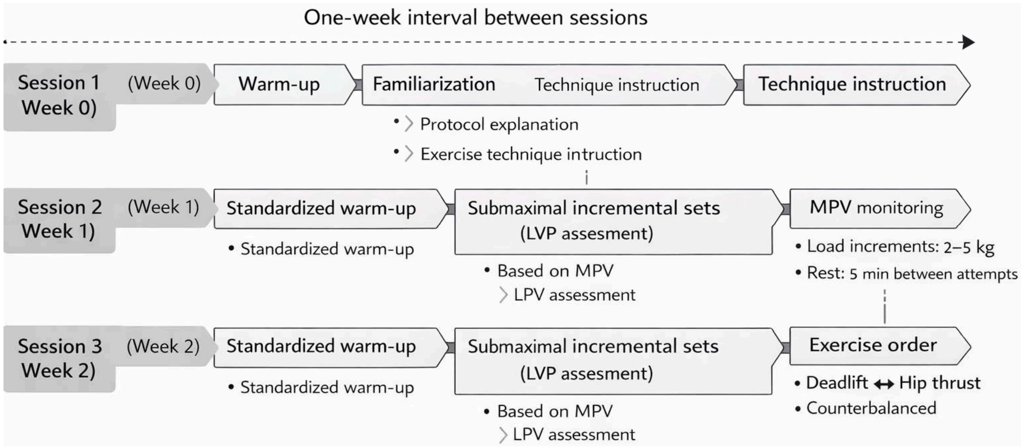

Figure 1. Study timeline design. Participants completed three sessions separated by one-week intervals.

2.2. Participants

An a priori sample size calculation was performed to determine the minimum number of participants required to detect meaningful differences in mechanical variables derived from the load–velocity profile. The analysis was conducted using G*Power software (version 3.1; Heinrich Heine University, Düsseldorf, Germany). Based on previous studies reporting large effect sizes for force–velocity and load–velocity outcomes in repeated-measures designs, a conservative effect size of Cohen's d = 0.8 was assumed [24,25]. The statistical power was set at 0.80 with an alpha level of 0.05. Under these assumptions, the minimum required sample size was estimated to be nine participants.

To increase the robustness of the reliability and validity analyses and to allow for sex-specific comparisons, a substantially larger sample was recruited. Accordingly, thirty-two participants were included in the final analysis, exceeding the minimum sample size requirement indicated by the power analysis (Table 1). Participants were recruited by convenience sampling. All participants were able to perform the deadlift with a minimum criterion of $\geq$1.5× body mass for men and $\geq$1.2× body mass for women. Relative one-repetition maximum values were as follows: men—deadlift (DL): 1.8 ± 0.3 kg·kg^{-1} and hip thrust (HT): 2.2 ± 0.3 kg·kg^{-1}; women—DL: 1.5 ± 0.2 kg·kg^{-1} and HT: 1.9 ± 0.3 kg·kg^{-1}. Furthermore, all participants had at least two years of experience performing both the hip thrust and deadlift exercises and engaged in structured resistance training a minimum of four days per week. They were also familiarized with the 1RM assessment and were free from any musculoskeletal injuries. The study protocol complied with the Declaration of Helsinki for Human Experimentation and was approved by the ethics committee at the Universidad Politécnica de Madrid, Spain (20210225). Written informed consent was obtained from each participant in advance.

Table 1. Anthropometric characteristics of the participants. Data are presented as mean ± standard deviation (SD).

	Men (n = 16)	Women (n = 16)
Age (years)	25.6 ± 3.8	25.1 ± 5.4
Body mass (kg)	75.8 ± 8.6	61.9 ± 4.3
Height (cm)	175.8 ± 7.3	165.1 ± 5.7

2.3. Procedure

2.3.1. Deadlift

A self-selected width with a mixed grip (one arm pronated and one arm supinated) was used. The deadlift was performed as a conventional deadlift, starting from the floor for all participants. The feet were positioned approximately shoulder-width apart, with both soles flat on the ground and toes pointing forward or slightly outward. Participants maintained a neutral spine, with their chest up, and head aligned with the torso throughout the lift. The barbell was lifted until full hip and knee extension, following standard technique guidelines.

2.3.2. Hip Thrust

In accordance with Contreras et al. [26], and as recently described by Dello Iacono et al. [27], the HT exercise was performed by having the subjects' upper back rest on a bench of 40 cm. Briefly, all participants positioned their upper backs on a bench, with feet placed slightly wider than shoulder-width apart and toes pointed either forward or slightly outward. A thick bar pad was used to cushion the barbell, which was positioned over the subjects' hips. They were instructed to thrust the bar upward while keeping a neutral spine and pelvis.

2.3.3. 1RM Testing and Load–Velocity Profiling

The participants first performed a 10 min general warm-up consisting of various dynamic mobilization exercises for the lower-body musculature. Then, 3 specific warm-up sets with progressively heavier barbell loads were performed. Individual load–velocity relationships and 1RM strength were determined using a progressive-loading test. Mean propulsive velocity (MPV) was tested due to strong correlations observed between MPV and load (%1RM) in previous studies [28,29]. The initial load was set at 20 kg and gradually increased using MPV as a parameter for adding load [30]. The next protocol was the following: initially, in increments of 20 kg until an MPV of 0.8 $m \cdot s^{-1}$ was reached, 3 repetitions were performed. Two repetitions were performed when the MPV was between 0.8 and 0.6 $m \cdot s^{-1}$ (10 kg increments), and only one repetition from that point until the end of the test. Increments of 5 kg were used when the MPV ranged from 0.6 to 0.5 $m \cdot s^{-1}$, and 2.5 kg increments were used when the MPV was less than 0.5 $m \cdot s^{-1}$ to 1RM. A lift was considered valid when the full range of motion was completed with the technique explained above. Inter-set rests were fixed at 3 min to reduce fatigue [31]. Only the best repetition (fastest and executed with the technique described above) at each load was considered for subsequent analysis. The Speed4Lift linear position transducer (Speed4Lift, Madrid, Spain) has been previously validated for measuring barbell velocity in resistance exercises. In the validation study by García-Ramos et al. [32], the Speed4Lift device was compared against a criterion reference system (a 3D motion capture system and the GymAware PowerTool) across multiple exercises, including the bench press, full squat, and prone bench pull. The results demonstrated excellent concurrent validity ($r = 0.97$–0.99; standard error of the estimate = 0.03–0.06 $m \cdot s^{-1}$) and high test–retest reliability (ICC = 0.97–0.99; coefficient of variation < 5%). These findings confirm that the Speed4Lift device provides accurate and reliable velocity measurements, supporting its suitability for use in the present study. Strong verbal encouragement was provided during all repetitions to motivate participants to give maximal effort.

2.4. Statistical Analyses

All data are presented as the mean ± standard deviation, where appropriate. The Shapiro–Wilk test was used to ensure normal distribution of the results. The one-repetition maximum (1RM) was estimated from a polynomial regression model between load and the terminal velocity (v_1RM), which was fixed for all participants, following values reported in the literature: 0.32 $m \cdot s^{-1}$ for the hip thrust and 0.16 $m \cdot s^{-1}$ for the deadlift [33]. The selection of a polynomial model was based on previous evidence indicating that the load–velocity relationship may deviate from strict linearity, particularly at higher loads approaching 1RM, where curvilinear behavior has been reported. Polynomial regression has been shown to better accommodate this non-linear pattern and to reduce estimation error when extrapolating maximal loads, compared with linear models [34–37]. Differences between sessions (session 1 vs. session 2) and sexes were assessed using two-way ANOVA. To establish criterion validity, Cohen's *d*, Pearson's correlation coefficient, linear regression and Bland–Altman plots were calculated between true and estimated 1RM. For relative reliability, the intraclass correlation coefficient (ICC) was used, and the standard error of measurement (SEM) and coefficient of variation (CV) were used as the main criterion for absolute reliability. The minimal detectable change (MDC) was calculated to determine the smallest change in measurements that could be considered significantly different from the measurement error [38]. The MDC was calculated using the following formula: $\text{MDC} = 1.96 \times \text{SEM} \times \sqrt{2}$. The ICC was interpreted following the recommendations of Koo and Li (2016), which set the following criteria: <0.5 low reliability, 0.50–0.75 moderate, 0.75–0.90 good, and >0.90 excellent based on the lower bound [39]. The magnitude of CV was based on the following parameters: poor (>10%), moderate (5–10%), or good (<5%) [40]. The MPV at each relative %1RM and 1RM estimation were considered reliable if they met the 3 following standards: good ICCs (>0.75), low CV ($\leq$10%), and a trivial or small ES (<0.60) based on the Hopkins modified Cohen scale ($\leq$0.2 [trivial], >0.2–0.6 [small], >0.6–1.2 [moderate], >1.2–2.0 [large], and $\geq$2.0 [very large]). Confidence limits were set at 95% for all reliability and validity analyses. All reliability assessments were performed using a custom-made Excel® spreadsheet, whereas all other statistical analyses were performed using the Jamovi statistical software package (version 2.3.18., Sydney, Australia). Statistical significance was set at $p \leq 0.05$.

3. Results

3.1. Validity 1RM Estimations

Thirty-two physically active adults voluntarily participated in the study, including sixteen men (age: 25.63 ± 3.79 years; body mass: 75.79 ± 8.64 kg; height: 175.81 ± 7.34 cm) and sixteen women (age: 25.06 ± 5.37 years; body mass: 61.94 ± 4.25 kg; height: 165.06 ± 5.72 cm). There was a moderate overestimation in 1RM deadlift ($p < 0.001$; mean difference (95% CI) = +2.68 kg (1.65 to 3.71); ES (95% CI) = 0.71 (0.41 to 1.01)) and a small overestimation for hip thrust ($p = 0.002$; mean difference (95% CI) = +3.29 kg (1.18 to 5.31); ES (95% CI) = 0.43 (0.15 to 0.71)).

For men, post hoc analysis showed a moderate overestimation in both the hip thrust ($p = 0.001$; MD (95% CI) = +5.64 kg (2.17 to 9.12); d (95% CI) = 0.66 (0.22 to 1.08)) and the deadlift ($p < 0.001$; MD (95% CI) = +3.24 kg (1.64 to 4.84); d (95% CI) = 0.82 (0.36 to 1.26)). In contrast, women only showed a moderate overestimation of 1RM in the deadlift ($p = 0.027$; MD (95% CI) = +2.14 kg (0.74 to 3.53); d(95% CI) = 0.61 (0.19 to 1.01)), but not in the hip thrust ($p = 0.301$; MD (95% CI) = +0.94 kg (−1.22 to 3.11); d(95% CI) = 0.17 (−0.21 to 0.55)).

Figure 2 shows the linear regressions between the actual 1RM value and its estimation for the three subgroups in each exercise. All linear regression models demonstrated a significant association between the actual value and the estimation ($p < 0.001$; $r^2 > 0.920$).

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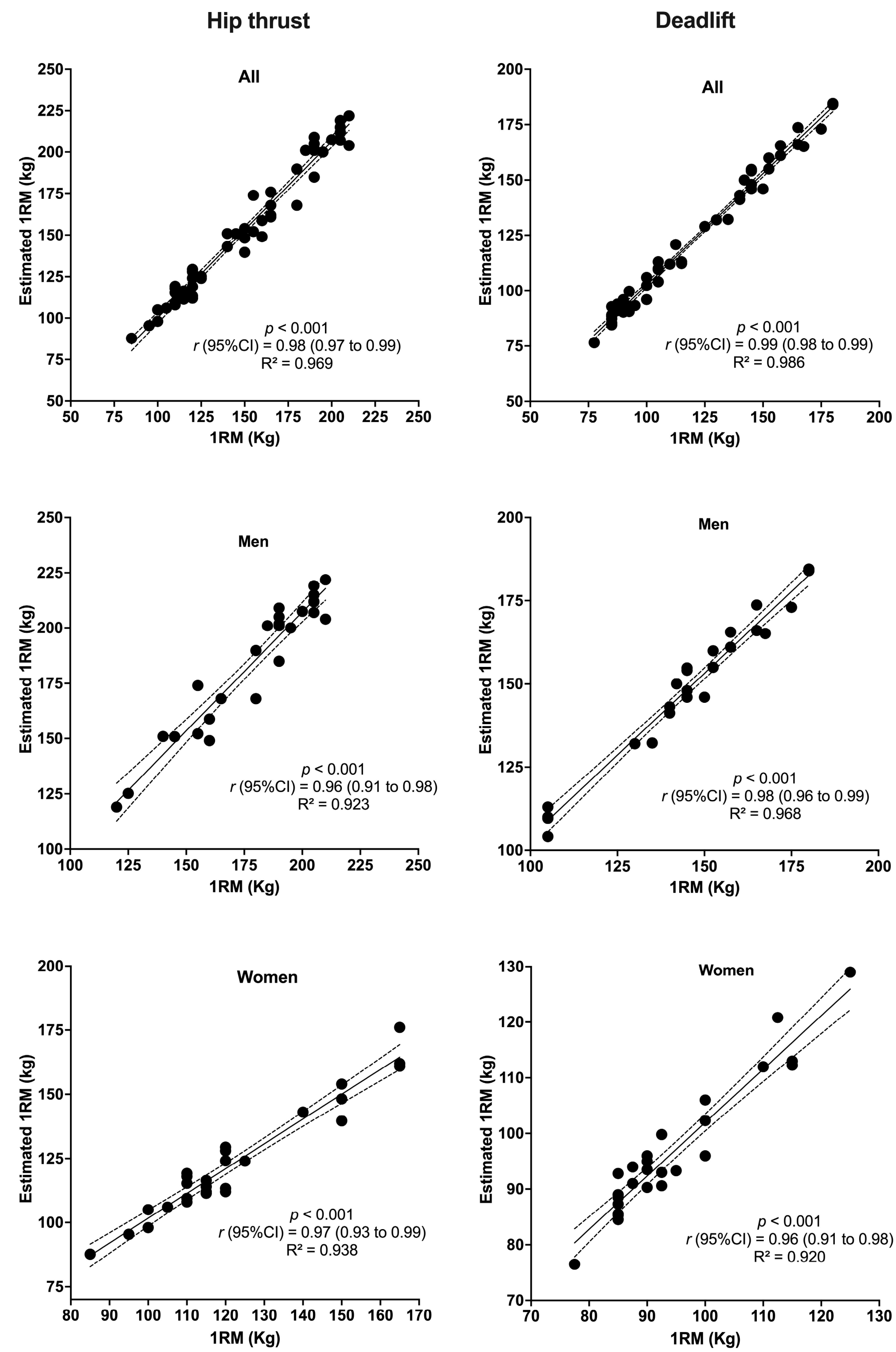

Figure 2. Relationship between predicted and actual one-repetition maximum (1RM) values for the hip thrust (HT, (**left**) panels) and deadlift (DL, (**right**) panels) exercises in all participants, men, and women. Each dot represents an individual data point. The *x*-axis indicates the measured 1RM (kg), and the *y*-axis shows the predicted 1RM (kg) obtained from the load–velocity profile. The solid line represents the line of best fit, while the dashed lines indicate the 95% confidence interval of the regression. The regression equation, *p*-value, and coefficient of determination (R^2) are shown for each subgroup.

Additionally, the Bland–Altman plots (Figure 3) indicated that the deadlift exhibited a smaller bias (+2.6 kg) compared to the hip thrust (+3.2 kg) for all participants. Although the difference in bias is small (0.6 kg), the limits of agreement for the hip thrust were wider than those for the deadlift, suggesting greater variability in the accuracy of the 1RM estimation.

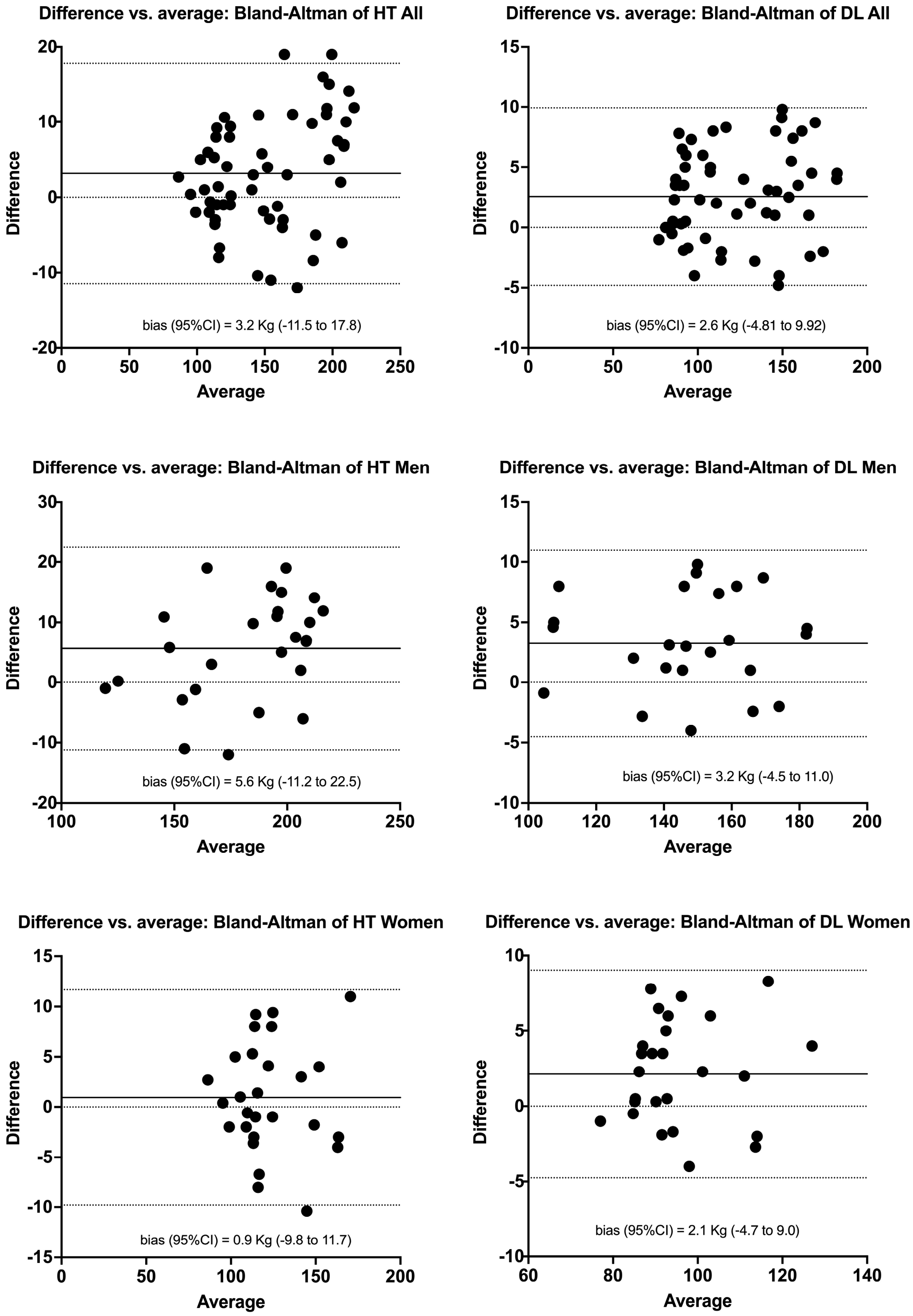

Figure 3. Bland–Altman plots showing the agreement between predicted and actual one-repetition maximum (1RM) values for the hip thrust (HT) and deadlift (DL) exercises in all participants, men, and women. Each point represents an individual data pair (predicted vs. measured 1RM). The y-axis indicates the difference between predicted and actual 1RM values (in kilograms), and the x-axis represents the mean of both measurements (in kilograms). The solid horizontal line represents the mean bias, and the dashed lines represent the 95% limits of agreement (bias $\pm$ 1.96 SD). Negative bias values indicate that predicted 1RM overestimated the actual 1RM.

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3.2. Test–Retest Reliability of the LVP and 1RM Estimations

The test–retest analysis at different loads for all participants showed that MPV associated with 1RM in the hip thrust was slightly lower in session 2 compared to session 1 ($p = 0.04$; ES = 0.38). No differences were observed in MPV for any of the analyzed loads in any subgroups for the deadlift ($p > 0.05$).

The reliability analysis for all participants indicated that the MPV with 30% of 1RM and at 1RM in the hip thrust (Table 2), as well as at 90% and at 1RM in the deadlift (Table 3), did not meet the minimum absolute and relative reliability criteria (ICC > 0.75, CV < 10% and ES < 0.60). However, when the analysis was performed by subgroups, it was found that the ICCs for MPV observed in men, both for the hip thrust and the deadlift, at all analyzed loads (i.e., 30%, 50%, 70%, 90%, and 100% 1RM) showed good to excellent relative reliability, with all values above 0.75 and CV% below 8.2% (Tables 2 and 3). In contrast, the relative reliability for women in the hip thrust at 30%, 70%, and 90% of 1RM was poor to moderate (ICC: 0.59 to 0.74), failing to meet the standards to be classified as reliable in this study. A similar trend was observed for the deadlift, where men demonstrated greater absolute reliability than women at each load (Table 3).

Table 2. Mean propulsive velocity (MPV), relative loads, and reliability metrics across sessions for hip thrust exercise.

Load (% 1RM)	Group	Session 1 M ± SD (m/s)	Session 2 M ± SD (m/s)	Difference in Mean (95% CI)		ICC (95% CI)		CV %	SEM (95% CI)		MDC	*p* Value	ES
30%	Male	0.92 ± 0.10	0.93 ± 0.10	0.01	(−0.01 to 0.04)	0.86	(0.69 to 0.94)	3.2	0.04	(0.03 to 0.06)	0.11	0.38	0.23
	Female	0.86 ± 0.09	0.87 ± 0.07	0.00	(−0.03 to 0.04)	0.59	(0.24 to 0.81)	4.9	0.05	(0.04 to 0.08)	0.14	0.85	0.04
	All	0.89 ± 0.10	0.90 ± 0.09	0.01	(−0.02 to 0.03)	0.70	(0.45 to 0.83)	4.1	0.05	(0.04 to 0.07)	0.14	0.49	0.12
50%	Male	0.75 ± 0.08	0.75 ± 0.07	0.00	(−0.01 to 0.03)	0.86	(0.70 to 0.94)	3.0	0.03	(0.02 to 0.04)	0.08	0.68	0.10
	Female	0.69 ± 0.07	0.68 ± 0.06	−0.01	(−0.03 to 0.01)	0.88	(0.73 to 0.95)	4.2	0.04	(0.03 to 0.06)	0.11	0.75	0.08
	All	0.72 ± 0.08	0.72 ± 0.07	0.00	(−0.02 to 0.02)	0.77	(0.57 to 0.87)	3.6	0.04	(0.03 to 0.05)	0.11	0.98	0.00
70%	Male	0.58 ± 0.06	0.57 ± 0.05	0.00	(−0.02 to 0.01)	0.85	(0.68 to 0.94)	3.3	0.02	(0.02 to 0.03)	0.06	0.70	0.10
	Female	0.52 ± 0.06	0.51 ± 0.06	−0.01	(−0.03 to 0.01)	0.73	(0.46 to 0.88)	4.9	0.03	(0.03 to 0.05)	0.08	0.28	0.28
	All	0.55 ± 0.07	0.54 ± 0.06	0.00	(−0.02 to 0.01)	0.85	(0.71 to 0.92)	4.1	0.03	(0.02 to 0.04)	0.08	0.26	0.20
90%	Male	0.41 ± 0.06	0.39 ± 0.06	−0.01	(−0.03 to 0.01)	0.81	(0.61 to 0.92)	5.1	0.03	(0.02 to 0.04)	0.08	0.27	0.28
	Female	0.35 ± 0.07	0.33 ± 0.07	−0.02	(−0.04 to 0.00)	0.74	(0.47 to 0.88)	9.1	0.04	(0.03 to 0.05)	0.11	0.13	0.41
	All	0.38 ± 0.07	0.36 ± 0.07	−0.01	(−0.02 to 0.01)	0.86	(0.73 to 0.92)	7.6	0.03	(0.02 to 0.04)	0.08	0.06	0.35
100%	Male	0.32 ± 0.07	0.30 ± 0.07	−0.01	(−0.03 to 0.01)	0.80	(0.58 to 0.91)	8.2	0.03	(0.02 to 0.05)	0.08	0.21	0.33
	Female	0.27 ± 0.08	0.24 ± 0.07	−0.03	(−0.05 to 0.00)	0.72	(0.44 to 0.87)	14.7	0.04	(0.03 to 0.06)	0.11	0.12	0.42
	All	0.29 ± 0.08	0.27 ± 0.08	−0.01	(−0.03 to 0.01)	0.84	(0.70 to 0.91)	12.2	0.03	(0.02 to 0.04)	0.08	0.04	0.38
Estimated 1RM (kg)	Male	189.0 ± 31.0	187.3 ± 31.6	1.66	(−7.66 to 11.0)	0.85	(0.68 to 0.94)	5.6	12.04	(−11.6 to 35.6)	33.4	0.71	0.09
	Female	123.9 ± 21.8	123.4 ± 18.7	0.44	(−7.39 to 8.27)	0.81	(0.58 to 0.92)	5.9	9.67	(−9.3 to 28.6)	26.8	0.91	0.03
	All	157.5 ± 42.1	156.4 ± 41.4	1.07	(−4.69 to 6.83)	0.93	(0.88 to 0.96)	5.7	10.96	(−10.5 to 32.4)	30.4	0.71	0.07

Note: SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval (upper, lower); SEM, standard error measurement; CV, coefficient of variation; 1RM, one-repetition maximum.

Table 3. Mean propulsive velocity (MPV), relative loads, and reliability metrics across sessions for the deadlift exercise.

Load (% 1RM)	Group	Session 1 M ± SD (m/s)	Session 2 M ± SD (m/s)	Difference in Mean (95% CI)		ICC (95% CI)		CV%	SEM (95% CI)		MDC	*p* Value	ES
30%	male	1.19 ± 0.13	1.19 ± 0.13	0.00	(−0.02 to 0.03)	0.91	(0.79 to 0.96)	2.6	0.04	(0.03 to 0.06)	0.11	0.66	0.11
	female	1.08 ± 0.10	1.06 ± 0.06	0.02	(−0.14 to 0.11)	0.91	(−0.09 to 1.00)	2.7	0.08	(0.05 to 0.22)	0.22	0.11	0.43
	All	1.14 ± 0.12	1.12 ± 0.12	0.02	(−0.02 to 0.03)	0.85	(0.76 to 0.95)	2.7	0.05	(0.04 to 0.07)	0.14	0.35	0.17
50%	male	0.92 ± 0.09	0.92 ± 0.10	0.00	(−0.03 to 0.02)	0.89	(0.71 to 0.92)	2.7	0.03	(0.03 to 0.05)	0.08	0.68	0.10
	female	0.84 ± 0.07	0.82 ± 0.04	0.02	(−0.07 to 0.06)	0.60	(0.10 to 1.00)	3.5	0.04	(−0.02 to 0.01)	0.11	0.09	0.45
	All	0.88 ± 0.09	0.87 ± 0.09	0.01	(−0.02 to 0.01)	0.87	(0.75 to 0.93)	3.1	0.03	(0.03 to 0.05)	0.08	0.13	0.28
70%	male	0.66 ± 0.06	0.65 ± 0.07	0.01	(−0.02 to 0.01)	0.91	(0.80 to 0.96)	2.4	0.02	(0.02 to 0.03)	0.06	0.31	0.26
	female	0.60 ± 0.05	0.59 ± 0.04	0.01	(−0.02 to 0.04)	0.87	(−0.02 to 0.96)	3.8	0.02	(0.01 to 0.05)	0.06	0.19	0.34
	All	0.63 ± 0.06	0.63 ± 0.06	0.00	(−0.01 to 0.01)	0.90	(0.80 to 0.94)	3.1	0.02	(0.02 to 0.03)	0.06	0.09	0.31
90%	male	0.39 ± 0.05	0.38 ± 0.05	0.01	(−0.02 to 0.00)	0.86	(0.70 to 0.94)	4.3	0.02	(0.02 to 0.03)	0.06	0.17	0.36
	female	0.36 ± 0.04	0.36 ± 0.06	0.00	(−0.05 to 0.11)	0.80	(−0.51 to 0.99)	7.5	0.05	(0.03 to 0.14)	0.14	0.68	0.10
	All	0.38 ± 0.05	0.37 ± 0.06	0.01	(−0.02 to 0.01)	0.72	(0.48 to 0.84)	5.9	0.03	(0.02 to 0.04)	0.08	0.27	0.20
100%	male	0.26 ± 0.05	0.25 ± 0.06	0.01	(−0.03 to 0.00)	0.81	(0.60 to 0.92)	8.1	0.03	(0.02 to 0.04)	0.08	0.21	0.33
	female	0.24 ± 0.05	0.24 ± 0.07	0.00	(−0.08 to 0.15)	0.55	(0.18 to 0.78)	12.8	0.07	(0.04 to 0.20)	0.19	0.94	0.02
	All	0.25 ± 0.05	0.24 ± 0.06	0.01	(−0.02 to 0.02)	0.58	(0.25 to 0.75)	10.4	0.04	(0.03 to 0.05)	0.11	0.45	0.14
Estimated 1RM (kg)	male	151.4 ± 21.8	150.9 ± 19.6	0.50	(−3.25 to 4.27)	0.95	(0.87 to 0.98)	2.7	4.84	(−4.7 to 14.3)	13.4	0.79	0.06
	female	96.2 ± 13.0	98.7 ± 12.9	−2.47	(−5.08 to 1.39)	0.93	(0.84 to 0.97)	3.2	3.63	(−3.5 to 10.7)	10.1	0.13	0.34
	All	123.8 ± 33.1	124.8 ± 31.1	−0.98	(−3.20 to 1.24)	0.98	(0.97 to 0.99)	3.0	4.28	(−4.1 to 12.7)	11.9	0.38	0.16

Note: M, Mean; SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval (upper, lower); SEM, standard error measurement; CV, coefficient of variation; 1RM, one-repetition maximum.

4. Discussion

This study aimed to examine the validity and reliability of individual load–velocity profiles in the deadlift and hip thrust exercises in men and women, with a specific focus on the absolute and relative reliability of movement velocity across submaximal loads, the reliability of 1RM estimation, and sex-specific differences in reliability metrics. The main results revealed that: (1) the load–velocity relationship was not sufficiently valid to accurately predict 1RM for all participants in deadlift and hip thrust exercises; (2) movement velocity at submaximal loads demonstrated good relative reliability (ICC > 0.75) and low variability (CV < 10%) in men across all loads for both exercises; (3) women showed slightly lower reliability, particularly at higher intensities, in both the hip thrust and deadlift; (4) the 1RM estimation exhibited good reliability in men and women, with consistent ICC and CV values for both exercises. Notably, the result showing that MPV at 1RM for the hip thrust was significantly lower in session 2 violates an assumption of reliability testing. This suggests a learning or fatigue effect, where participants may have either improved their technical execution in the first session or experienced cumulative neuromuscular fatigue by the second session, affecting maximal velocity output. Such effects highlight the importance of considering familiarization sessions or recovery status when assessing MPV at maximal loads. These findings indicate that while the LVP may not provide accurate 1RM predictions, it remains a valuable and reproducible method for longitudinal performance monitoring. From a physiological and neuromuscular perspective, reduced reliability and validity at higher loads may be explained by increased variability in motor unit recruitment, firing frequency, and synchronization as maximal force production is approached [41,42]. At near-maximal intensities, small fluctuations in neural drive or fatigue status can produce disproportionate changes in movement velocity, thereby affecting both the slope and intercept of the load–velocity relationship.

It has been established that the combined use of both heavy and light loads contributes to greater 1RM prediction validity and reliability [6]. However, our findings indicate that 1RM predictions systematically overestimate the actual 1RM in deadlift and hip thrust. This overestimation may stem from model-related factors (e.g., linear regression assumptions, limited load points) and physiological variability, particularly in the minimal velocity threshold (MVT), which can differ across individuals. The presence of a proportional bias in the hip thrust suggests that stronger participants experienced greater overestimation, possibly due to differences in bar path stability, hip extension mechanics, or load distribution compared with the deadlift. Results from Ruf et al. [4] suggest that 1RM predictions also overestimate the actual 1RM, with typical errors of estimates ranging between 9.1 and 13.7 kg in deadlift in resistance-trained athletes. In this vein, this study predicted deadlift 1RM to an unacceptable degree, with error up to 18.5 kg [43]. Moreover, Banyard et al. [33], reported that all predicted 1RMs (with three loads (20, 40, 60% of 1RM), four loads (20, 40, 60, 80% of 1RM), or five loads (20, 40, 60, 80, 90% of 1RM) were significantly different from the actual 1RM in squat. In contrast, our data showed a smaller and statistically nonsignificant overestimation in the hip thrust, consistent with Dello Iacono et al. [27], who found an excellent agreement between the test and retest trials' load–velocity profile in hip thrust with a Smith machine. Accordingly, some authors proposed that the reliability of the 1RM test may vary between resistance-trained and untrained individuals [44]. For this reason, the discrepancies in results across studies may be partially attributed to the differing levels of training experience among the participants. Furthermore, the author explains in this systematic review that the reliability could be exercise- or body-region-dependent [45]. From a morphofunctional standpoint, free-weight exercises require greater intermuscular coordination, trunk stabilization, and control of joint kinematics, all of which may increase trial-to-trial variability in movement velocity, particularly at higher loads [41,42].

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Beyond differences in training experience, discrepancies with de Hoyo et al. [14] may also stem from methodological divergences in how prediction models were constructed and applied. While de Hoyo et al. measured velocity during the barbell hip thrust using a Smith machine—minimizing bar path variability and improving signal stability—the present study employed free-weight versions of the exercises, which introduce greater mechanical variability and affect both the slope and intercept of the load–velocity relationship. Additionally, de Hoyo et al. implemented multi-point regression models supported by high-precision velocity measurement devices and controlled load progressions, whereas our analysis relied on submaximal loads that exhibited greater variability at higher intensities, particularly in women. Differences in modeling assumptions (e.g., individualized vs. fixed minimal velocity thresholds, strictly linear vs. polynomial relationships), measurement systems, and biomechanical constraints likely contributed to the divergent accuracy in 1RM predictions observed between studies. These methodological factors, therefore, play a central role in explaining the inconsistencies and highlight the importance of considering exercise selection, instrumentation, and regression structure when interpreting LVP-based 1RM estimates.

Regarding the linear regression model, it demonstrated a significant association between the actual value and the estimation, presenting good accuracy ($r^2 > 0.920$). These results are in agreement with previous studies that identified a relationship between the movement velocity and %1RM for lower-body (squat, deadlift) and upper-body (bench press) compound exercises. For instance, the overall validity of studies focused on the bench press [46,47] demonstrates a strong correlation between the L-V relationship and 1RM. Conversely, results for squat and deadlift exercises appear inconsistent [5,48]. Researchers attribute this variation in the results of lower-body exercises to several factors. While we emphasize the importance of standardization practices in our measurements, we particularly associate the discrepancies in reliability and validity outcomes with specific reasons [5]. Weakley et al. (2021) note that the differences in the precision of 1RM estimation are due to the greater technical complexity of squat and deadlift exercises compared to upper-body exercises [49]. The magnitude of these errors highlights the importance of individualized velocity profiling rather than the use of generalized prediction equations.

Although the reasons for the differences in predicted and actual 1RM remain unclear, the high variability in MPV at 1RM might be related to these discrepancies. Current data indicate that the mean propulsive velocity at relative loads is influenced by high loads in both sexes and across both exercises, demonstrating poor absolute and relative reliability (ICC < 0. 75 and CV > 10%). In particular, women demonstrated lower levels of reproducibility in DL (ICC = 0.55; CV = 12.8%) and HT (ICC = 0.72; CV = 14.7%) than men (DL = ICC = 0.81; CV = 8.1%; HT = ICC = 0.80; CV = 8.2%) at 100% 1RM. The poor reliability of MPV at 100% 1RM observed in the present study is also in accordance with recent research in the free-weight back squat exercise in men population (ICC = 0.42; CV = 22.5%) [33]. To our knowledge, no studies included men and women in the reliability analysis of MPV in the L-V relationship. Therefore, even though MPVs are reliable for moderate to low loads (30, 50, 70% 1RM) in the present study and in other studies [33], it would be interesting to analyze if the same results are present in other exercises. Regarding sex differences, men displayed higher reproducibility across all loads than women. This could be explained by known neuromuscular and biomechanical differences, such as greater muscle cross-sectional area, higher proportion of type II fibers, and enhanced motor unit synchronization in men [41]. In contrast, women may exhibit greater variability in velocity output at high intensities due to differences in muscle stiffness, hormonal regulation, or technical consistency under heavy loads. Although a previous systematic review found no significant sex differences in 1RM test reliability [9], our data suggest that exercise-specific mechanical factors may interact with biological sex, influencing reproducibility outcomes.

Finally, minimal detectable change (MDC) is defined as the smallest change in a variable that indicates a true change in performance [50]. MDC is particularly significant when monitoring athletes across multiple trials, as variation between trials may indicate a change that has not surpassed a threshold error [51]. To enhance interpretability, MDC values were expressed both in absolute and relative terms (% of the mean), allowing coaches to gauge meaningful performance variations. González Badillo et al. (2011) [46] proposed the load ~1.00 m/s^{-1} MPV (corresponding to 75% 1RM) as the reference for monitoring performance variations or to quantify the neuromuscular fatigue. Additionally, research conducted by Navarro et al. [20] used the velocity attained against 75% 1RM loads in bench press and squat exercises after three different protocols of training [3 × 5 (10), 6 × 5 (10), and 3 × 10 (10)] for 4 weeks. In this line, Moura et al. (2024) [22] compared the acute responses (after the intervention +5 min, and +20 min) of post-fatigue exercise in free parallel back squat, analyzing changes in MPV against three load intensities (40, 60, and 80% 1RM). Moura et al. (2024) revealed variations after fatigue protocol on MPV of 0.04 to 0.11 m/s^{-1}, whereas our data suggest MDC in MPV of 0.06 to 0.14 m/s^{-1} in deadlift and hip thrust. The results of our study highlight that it is essential to verify the test–retest reliability before using an MPV test, when they are used to monitor neuromuscular fatigue or performance variations, to determine whether the changes are real or simply a result of testing errors or biological variations.

Some study limitations should be acknowledged. Firstly, all tests in this study were performed with free weights. 1RM prediction of free-weight exercises possesses other kinetic and kinematic movement characteristics, as there is typically more movement in the sagittal plane and a higher range of motion when using free weights compared with a Smith machine [52]. This trade-off should be recognized as a methodological choice rather than a constraint. Although ICC values generally indicated good reliability at submaximal loads, some confidence intervals were notably wide, particularly for the female 30% DL condition. Such wide intervals, which even included values near zero, reflect substantial statistical uncertainty, likely due to small sample size and low between-subject variability, emphasizing that relying solely on the point estimate may overstate reliability. Some limitations of this study should be acknowledged. First, all tests were performed using free-weight exercises, which may introduce greater mechanical variability compared with Smith machine protocols and affect load–velocity relationships. Second, although reliability was generally acceptable at submaximal loads, some conditions—particularly in women and at higher intensities—showed wide confidence intervals, reflecting increased uncertainty. Finally, differences in strength training background among participants may limit the generalizability of the findings to more homogeneous or elite populations.

Practical Applications

Load–velocity profiling can be confidently applied in men across a wide range of submaximal loads in both the deadlift and hip thrust, as movement velocity showed good reliability. In women, greater caution is required, particularly at higher relative loads (≥70–100% 1RM), where reliability was reduced. Therefore, low-to-moderate loads (30–70% 1RM) are recommended when using velocity-based monitoring in female athletes. Additionally, the deadlift demonstrated greater reliability than the hip thrust across sexes and may be preferred for monitoring purposes, especially when free weights are used.

5. Conclusions

Individual load–velocity profiles did not demonstrate sufficient validity for accurate 1RM estimation in the deadlift and hip thrust, as systematic overestimation was observed. However, movement velocity showed good reliability at submaximal loads, particularly in men, supporting the use of load–velocity profiling for longitudinal performance monitoring. Sex- and exercise-specific differences in reliability highlight the need for cautious interpretation of near-maximal loads, especially in women.

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