EVALUATING LIFTING VELOCITY FOR PREDICTING ONE-REPETITION MAXIMUM IN THE CLEAN AND JERK

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Abstract:

We examined whether lifting velocity can serve as an objective indicator for predicting clean and jerk one-repetition maximum (1RM). Fourteen competitive adolescent male weightlifters completed two sessions, each involving an incremental loading test at 50%, 70%, 80%, and 90% of 1RM, followed by load increases until reaching actual 1RM. Peak velocity (PV) was recorded for all lifts using a GymAware device. In the second session, 1RM was predicted using the individual load–PV relationship derived from three exercise phases (clean, jerk, and the entire movement) combined with either the actual or optimal minimal velocity threshold (MVT) from the first session. Absolute errors from the test-retest of the actual 1RM (5.0 kg) were not significantly different to those from all velocity-based methods (range = 6.3–10.2 kg; p=.158–0.730), except for the larger errors obtained for the clean phase combined with the actual MVT (10.1 kg p=.008). Random errors for the actual 1RM (15.7 kg) fell within the range of velocity-based methods (13.2–23.1 kg). These results suggest that, although a direct assessment of the actual 1RM remains the most accurate method, measuring PV during warm-up sets may serve as a supplementary tool for guiding the selection of initial attempts in weightlifting competitions.

Keywords: *maximal dynamic strength, velocity-based training, weightlifting*

Introduction

Competitive weightlifting, as an Olympic sport, is becoming increasingly popular worldwide (Storey & Smith, 2012). In competition, athletes aim to lift the heaviest weight in snatch, clean and jerk, or their combined total within a particular bodyweight category (Sandau, Chaabene, & Granacher, 2022). The heaviest successful lift is also defined as the one-repetition maximum (1RM), which is widely regarded as the gold standard for assessing maximal dynamic strength (Todd, Shurley, & Todd, 2012). The IWF Level 2 Coaching Manual recommends that the opening attempt should be determined based on multiple factors, including competition history, the athlete's ability to cope with competitive stress, tactical considerations, and other relevant factors (https://iwf.sport/downloads/; Kwan & Helms, 2022; Storey, Birch, Fan, & Smith, 2016; Williams, Clarke, Aspe, Cole, & Hughes, 2017). Considering the multifactorial nature of weightlifting performance, incorporating additional objective markers may help coaches to select attempt weights more accurately and improve the success rate of the opening attempt.

Velocity-based methods have gained popularity as an alternative to the traditional 1RM testing, particularly in common resistance exercises such as the bench press (Janicijevic, Jukic, Weakley, & García-Ramos, 2021), back squat (Chen, Xiao, Mao, Zhang, & García-Ramos, 2025), and deadlift (Janicijevic, Şentürk, Akyildiz, Gu, & García-Ramos, 2024). Among these methods, the most accurate approach for estimating 1RM involves assessing the individual load–velocity relationship

and then applying a linear regression equation to estimate the 1RM as the load corresponding to the predefined minimal velocity threshold (MVT) (García-Ramos, 2023b). For this purpose, either the lifting velocity associated with a previously assessed individual 1RM (i.e., actual MVT) or the average 1RM velocity reported across participants in prior studies (i.e., general MVT) has been used (Janicijevic, et al., 2021). Moreover, García-Ramos (2023a) recently proposed the concept of an optimal MVT, defined as the velocity threshold that would eliminate discrepancies between actual and predicted 1RM values within the same testing session. Existing research has shown that the optimal MVT provides more accurate 1RM predictions than the traditional (actual and general) MVTs in both the bench press (García-Ramos, 2023a) and back squat (Chen, et al., 2025; Fitas, et al., 2024a). Therefore, it is worthwhile to investigate whether the optimal MVT can similarly enhance 1RM prediction accuracy in weightlifting exercises. If confirmed, this approach could provide weightlifting coaches with objective data to guide attempt selection in competitions.

The accuracy of 1RM prediction may depend on the reliability of the MVT used in the estimation process (Chen, et al., 2025). Thompson, Rogerson, Ruddock, Banyard, and Barnes (2021) found that the actual MVT of the power clean demonstrated high reliability in competitive weightlifters, although they did not investigate its accuracy for 1RM prediction. Previous studies have shown that the optimal MVT demonstrates higher reliability than the actual MVT (Chen, et al., 2025; Fitas, et al., 2024a; García-Ramos, 2023a), which may contribute to improved accuracy in 1RM prediction. However, existing research on the optimal MVT just focused on traditional exercises (Chen, et al., 2025; Fitas, et al., 2024a; García-Ramos, 2023a; Janicijevic, et al., 2024; Miras-Moreno & García-Ramos, 2024). Therefore, whether the optimal MVT can demonstrate higher reliability than the actual MVT in the clean and jerk, and whether it can provide more accurate 1RM predictions, warrants further investigation. It is important to note that mean velocity (MV) is not suitable for monitoring the snatch and the clean and jerk, as both exercises involve two distinct upward movement phases. In addition, evidence suggests that peak velocity (PV) is more accurate in the power clean 1RM estimation than MV (Haff, García-Ramos, & James, 2020). Therefore, PV, rather than MV, should be used when calculating the optimal MVT and predicting 1RM in weightlifting exercises. Unlike the snatch or power clean, overall performance in the clean and jerk is determined by both the clean and the jerk phases. As such, when establishing load–PV relationship for the clean and jerk, three PV values can be identified—corresponding to the clean phase, the jerk phase, and the entire movement. However, it remains unclear which of these PV measures provides the most accurate prediction of 1RM in the clean and jerk.

The aim of this study was to evaluate whether velocity-based predictions obtained within-session offer greater accuracy in estimating the clean and jerk 1RM than using *a prior* direct 1RM measurement. Given the high test–retest reliability of 1RM measurements (Grgic, Lazinica, Schoenfeld, & Pedisic, 2020) and the concerns raised in some studies regarding the accuracy of velocity-based methods to predict 1RM in complex exercises (Fitas, et al., 2024a; Haff, et al., 2020; Jukic, García-Ramos, Malecek, Omcirk, & Tufano, 2022), we hypothesized that the previously measured actual 1RM would provide a more accurate estimate of current performance than velocity-based predictions obtained during the same session. Additionally, we examined the between-session reliability of both the actual MVT and the optimal MVT, as well as their accuracy in predicting the clean and jerk 1RM when combined with the clean phase, the jerk phase, or the entire movement. We hypothesized that the optimal MVT would demonstrate greater between-session reliability and 1RM prediction accuracy than the actual MVT (Chen, et al., 2025; Thompson, et al., 2021), while no specific hypothesis was proposed for the exercise phase due to the limited evidence available.

Methods

Participants

Considering previous research on the power clean (Haff, et al., 2020), which reported a large effect size difference between the actual MVT and the theoretical MVT (i.e., the optimal MVT), we used a *f* effect size of 0.4, an α error probability of 0.05, a power of 0.80, two groups, three measurements, and an assumed correlation of 0.5 (default value) among repeated measures. The sample size calculation indicated that at least 12 participants were required to detect the expected effects (G*Power software, version 3.1.9.6). Fourteen male competitive adolescent weightlifters (age: 15.9 ± 0.9 years; body height: 1.70 ± 0.62 m; body mass: 67.6 ± 9.3 kg; clean and jerk record within a month: 122.4 ± 18.9 kg) were recruited for this study. All participants had received professional and systematic weightlifting training (5.1 ± 0.9 years) at a local weightlifting school and were proficient in weightlifting techniques. No physical limitations or musculoskeletal injuries that could compromise weightlifting performance were reported. Participants and their parents and coaches were informed of the procedures and signed a written informed consent form before initiating the study. The study protocol adhered to the tenets of the Declaration

of Helsinki and was approved by the Institutional Review Board (Jimei University; IRB approval: JMU202411088).

Study design

A repeated-measures design was used to assess the accuracy of different velocity-based methods for predicting clean and jerk 1RM. Participants completed two testing sessions separated by one week. Each session began with lifts at 50%, 70%, 80%, and 90% of their best clean and jerk performance from the previous month, followed by progressive load increases until their 1RM for that day was directly determined. Between-session reliability was assessed for the actual MVT and optimal MVT, considering three PV measurements derived from the clean phase, jerk phase, and the entire movement. To evaluate the accuracy of 1RM prediction, the actual MVT and optimal MVT—all derived from session one—were used to predict 1RM in session two. All testing was conducted at 4 p.m. during participants' regular training sessions under consistent environmental conditions (~20°C, ~65% humidity).

Procedures

Testing sessions. Each testing session began with a 10-minute warm-up, which was part of the participants' regular pre-training routine. This included dynamic stretching targeting the major joints involved in weightlifting movements, specifically the ankle, hip, and shoulder joints, to enhance mobility and prepare the muscles for explosive actions. In addition, participants performed weightlifting technique drills with an empty barbell to reinforce movement patterns before testing. After a 3-minute rest, participants commenced the incremental load testing protocol. The protocol consisted of three lifts at 50% (60.9 ± 9.4 kg), two lifts at 70% (85.8 ± 13.4 kg), one lift at 80% (97.9 ± 14.8 kg) and one lift at 90% (109.9 ± 16.8 kg) of their previous clean and jerk 1RM record. The load was then progressively increased in 1-5 kg increments until participants achieved their actual 1RM. Consistent with their regular training routine, participants rested approximately 1-minute between repetitions and 3-minutes between load increases. The execution standards for the clean and jerk in this study were consistent with the International Weightlifting Federation rules (https://iwf.sport/weightlifting_/rules/). In the present study, the type of jerk was not standardized, allowing participants to use their habitual technique. Accordingly, 13 participants performed the split jerk, while one participant used the squat jerk.

Measurement equipment and data analysis. An Olympic barbell and weight plates (ZKC, Cangzhou, China) were used in all testing sessions, coupled with a linear position transducer (GymAware RS, Kinetic Performance Technology, Canberra, Australia), which has demonstrated to be valid for monitoring lifting velocity in weightlifting exercises (Thompson, et al., 2021). The linear position transducer was positioned on the ground to the left of the participants' feet, with the Velcro strap attached to the left end of the barbell, ensuring that the athlete's technical movements were not obstructed. By cross-referencing the synchronized vertical position- and velocity-time curves in the GymAware cloud platform, the PVs for the clean phase and jerk phase were specifically extracted from their respective upward concentric phases.

For each load, only the fastest repetition (considering the entire movement) was considered for analysis. The actual MVT was defined as the PV recorded during the 1RM lift of that session. The absolute loads corresponding to 50%, 70%, 80%, and 90% of each participant's previous best clean and jerk and their associated PVs were used to create three linear regression models (clean phase, jerk phase, and entire movement), determining the load-axis intercept and slope of the load–PV relationship. For the entire movement model, the PV at each load was the fastest value from either the clean or jerk phase, which could vary by load and participant. The optimal MVT was then calculated by solving for velocity using the actual 1RM load in the load–PV equation:

$$\text{optimal MVT} = (\text{actual 1RM} - \text{load intercept})/\text{slope}$$

(Chen, et al., 2025; García-Ramos, 2023a; Miras-Moreno & García-Ramos, 2024). In the second session, new load–PV relationships were developed using the same procedure. The 1RM for the second session was predicted by applying the MVTs from the first session.

Statistical analyses. Descriptive data were assessed for normal distribution using the Shapiro-Wilk test and are presented as means and SD (normal distribution) or medians and IQR (non-normal distribution). Test-retest reliability was assessed using the intraclass correlation coefficient (ICC; model 3.1) and the coefficient of variation (CV = standard error of measurement / participants' mean score × 100) (Hopkins, 2015). The goodness-of-fit of individual load–PV relationships was evaluated using the coefficient of determination (r^2). To assess whether the velocity-based methods were equivalent to the "gold-standard" method, the Wilcoxon signed-rank test was used to compare the absolute errors (kg) of the six predicted 1RMs with the between-session absolute difference of the actual 1RM. Additionally, generalized estimating equations (GEE) were conducted to compare raw and absolute errors in 1RM prediction across different MVT types (actual *vs.* optimal) and exercise phases (clean *vs.* jerk *vs.* entire movement). When significant main or interaction effects were detected, Bonferroni *post-hoc* comparisons were performed. Bland-Altman anal-

ysis was used to assess systematic bias, random error, and proportional bias. Acceptable reliability was determined as an ICC > 0.75 and CV < 10%. Proportional bias was considered present when a significant linear regression was observed between the mean of the predicted and actual 1RM and the raw error (Bland & Altman, 1999). Statistical analyses were performed using SPSS software (version 27.0, SPSS Ins., Chicago). Alpha was set at 0.05.

Results

All variables demonstrated acceptable between-session reliability, except for all the actual MVTs (ICC = 0.46–0.51) and the optimal MVT derived from the clean phase (ICC = 0.68) (Table 1). The goodness-of-fit (r^2) of the individual load–PV relationships ranged from 0.956–0.971 for the clean phase, 0.942–0.944 for the entire clean and jerk movement, and 0.790–0.900 for the jerk phase.

The absolute errors derived from the test-retest of the actual 1RM were not significantly different from the errors of all velocity-based methods (p=.158–0.730) with the only exception of the larger errors for the clean phase combined with the actual MVT (p=.008). To provide a practical reference for weightlifting coaches, absolute errors are additionally reported as a percentage of the actual 1RM in Table 2.

Regarding the comparison across the velocity-based methods, the GEE revealed a significant interaction between exercise phase and MVT type for absolute error (χ^2 = 8.645, p=.013) and raw error (χ^2 = 9.164, p=.010). The actual MVT derived from the entire movement significantly reduced absolute

Table 1. Between-session reliability of the basic data

Phase	Variable	Session 1	Session 2	ICC (95%CI)	CV (95%CI), %
Clean	$V_{50,}$ m·s^{-1}	2.21 ± 0.15	2.22 ± 0.12	0.86 (0.61, 0.95)	2.48 (1.80, 3.99)
	V_{70}, m·s^{-1}	2.00 ± 0.12	1.99 ± 0.12	0.83 (0.55, 0.94)	2.78 (2.02, 4.48)
	V_{80}, m·s^{-1}	1.85 ± 0.13	1.87 ± 0.11	0.85 (0.60, 0.95)	2.67 (1.94, 4.30)
	V_{90}, m·s^{-1}	1.70 ± 0.12	1.71 ± 0.13	0.85 (0.60, 0.95)	3.01 (2.18, 4.85)
	Actual MVT, m·s^{-1}	1.57 ± 0.12	1.60 ± 0.12	**0.46 (−0.07, 0.79)**	5.70 (4.13, 9.19)
	Optimal MVT, m·s^{-1}	1.62 ± 0.12	1.63 ± 0.15	**0.68 (0.26, 0.89)**	4.94 (3.58, 7.96)
Jerk	$V_{50,}$ m·s^{-1}	2.11 ± 0.17	2.10 ± 0.18	0.93 (0.80, 0.98)	2.41 (1.75, 3.89)
	V_{70}, m·s^{-1}	2.02 ± 0.13	2.03 ± 0.16	0.94 (0.82, 0.98)	1.96 (1.42, 3.15)
	V_{80}, m·s^{-1}	1.96 ± 0.14	1.95 ± 0.14	0.92 (0.77, 0.97)	2.28 (1.65, 3.67)
	V_{90}, m·s^{-1}	1.86 ± 0.13	1.87 ± 0.12	0.86 (0.61, 0.95)	2.69 (1.95, 4.34)
	Actual MVT, m·s^{-1}	1.79 ± 0.13	1.75 ± 0.16	**0.47 (−0.06, 0.79)**	6.16 (4.46, 9.92)
	Optimal MVT, m·s^{-1}	1.83 ± 0.14	1.84 ± 0.13	0.87 (0.63, 0.95)	2.91 (2.11, 4.68)
Entire	$V_{50,}$ m·s^{-1}	2.21 ± 0.15	2.25 ± 0.12	0.77 (0.42, 0.92)	3.09 (2.24, 4.98)
	V_{70}, m·s^{-1}	2.06 ± 0.13	2.07 ± 0.13	0.91 (0.73, 0.97)	2.16 (1.56, 3.47)
	V_{80}, m·s^{-1}	1.96 ± 0.14	1.97 ± 0.14	0.94 (0.83, 0.98)	1.83 (1.32, 2.94)
	V_{90}, m·s^{-1}	1.86 ± 0.13	1.87 ± 0.12	0.89 (0.68, 0.96)	2.45 (1.78, 3.94)
	Actual MVT, m·s^{-1}	1.80 ± 0.13	1.75 ± 0.16	**0.51 (−0.01, 0.81)**	5.94 (4.31, 9.57)
	Optimal MVT, m·s^{-1}	1.79 ± 0.16	1.81 ± 0.16	0.88 (0.68, 0.96)	3.33 (2.41, 5.36)
	1RM, kg	120.6 ± 17.7	119.5 ± 18.5	0.92 (0.76, 0.97)	4.73 (3.43, 7.62)

Note. Data are presented as means ± SD. 1RM indicates one-repetition maximum; 95%CI, 95% confidence intervals; CV, within-subject coefficient of variation; ICC, intraclass correlation coefficient; MVT, minimal velocity threshold; V50–90, peak velocities corresponding to 50–90% of the participant's record.

Table 2. Wilcoxon signed-rank test comparing the absolute errors (kg) of different velocity-based one-repetition maximum (1RM) estimation methods with the between-session absolute difference of the actual 1RM

Method	Actual 1RM	Actual MVT			Optimal MVT		
		Clean	Jerk	Entire	Clean	Jerk	Entire
Median (IQR), kg	5.0 (7.0)	10.1 (14.1)	6.5 (12.5)	6.3 (7.9)	7.5 (10.2)	10.2 (10.4)	7.9 (8.2)
Median (IQR), %	3.8 (5.1)	8.8 (12.0)	5.7 (9.6)	5.1 (6.3)	6.1 (7.7)	7.5 (9.4)	6.8 (7.7)
Z	/	2.668	1.099	0.345	1.161	1.412	0.785
p	/	**0.008***	0.272	0.730	0.245	0.158	0.433

Note. 1RM, 1-repetition maximum; MVT, minimal velocity threshold.

error compared to the actual MVT derived from the clean phase (p=.039), and significantly reduced raw error in the entire movement compared to the jerk phase (p=.026). In contrast, the optimal MVT significantly reduced raw error in both the clean phase and jerk phase compared to the actual MVT (p=.029–0.038). No other comparisons reached statistical significance (p=.062–1.000). Overall, the optimal MVT showed the lowest raw error (0.4 ± 3.0 kg), while the actual MVT yielded the lowest absolute error (5.3 ± 1.0 kg) when combined with the entire movement (Figure 1).

Random errors derived from the test-retest of the actual 1RM (15.7 kg) fell within the range of velocity-based methods (13.2–28.4 kg). Proportional bias was not observed for any velocity-based method (r^2 = 0.000–0.199, p=.110–0.982) neither for the test-retest of the actual 1RM (r^2 = 0.010, p=.730) (Figure 2; Figure 3).

Discussion and conclusions

Except for the actual MVT combined with the clean phase, all other velocity-based methods showed comparable accuracy to the use of a previously measured 1RM for selecting clean and jerk attempts. Among the velocity-based estimation methods, the load–PV relationship derived from the entire clean and jerk movement yielded the lowest absolute error when using the actual MVT (5.3 kg), and the lowest raw error when using the optimal MVT (−0.4 kg). However, a lower reliability of the actual MVT compared to the optimal MVT may lead to greater variability in its predictive accuracy. This was evident in the fact that the actual MVT from session 1 (1.80 m·s^{-1}) was more similar to the optimal MVT from session 2 (1.81 m·s^{-1}) than to the actual MVT from session 2 (1.75 m·s^{-1}). The random errors associated with velocity-based methods (13.2–23.1 kg) were within the range of the test-retest of the actual 1RM (15.7 kg). These findings suggest that, although direct assessment of the actual 1RM remains the most accurate method, measuring PV during warm-up sets may serve as a practical supplementary tool for guiding the selection of initial attempts in weightlifting competitions.

From the perspective of exercise phases, using the entire clean and jerk movement rather than isolated phases may better capture the determinants of 1RM performance based on current findings. One explanation lies in the unique structure of the clean and jerk, which comprises two distinct phases (Sandau, Langen, & Nitzsche, 2023). Unlike the snatch, performance in the clean and jerk is influenced by the athlete's limiting factor—either the clean or the jerk—which varies between individuals. Some lifters reach their maximum capacity during the clean, while others are limited in the jerk. Furthermore, mechanical differences between

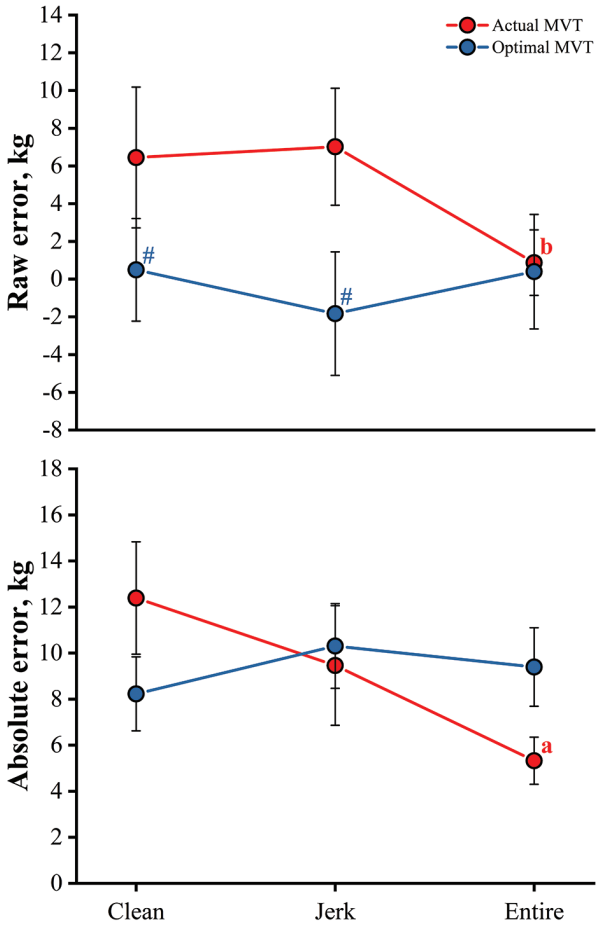


Figure 1. Post-hoc comparisons of raw error (upper-panel) and absolute error (lower-panel) for one-repetition maximum prediction across different exercise phases (clean, jerk, entire) and minimal velocity threshold (MVT) types (actual, optimal). [a] indicates a significant difference from the clean phase; [b] indicates a significant difference from the jerk phase; [#] indicates a significant difference from the actual MVT.

submaximal and maximal loads may contribute to prediction error. During lighter clean attempts, athletes tend to generate higher PV after the second pull and catch the bar at a higher position, requiring only a shallow squat. At 1RM, the bar achieves lower PVs, necessitating a deeper squat to complete the lift (Sandau, et al., 2023). The goodness-of-fit in the jerk phase was lower compared to the other two exercise phases observed in this study. In some participants, PV exhibited minimal variation across loads during the jerk, indicating that this phase was not the limiting factor for this specific population. This further contributed to potential prediction errors when using jerk phase data alone. These results suggest that integrating both exercise phases may improve the accuracy of 1RM prediction in the clean and jerk.

Current results supported the notion that the optimal MVT demonstrated greater between-session reliability compared to the actual MVT. Thompson et al. (2021) previously demonstrated that the actual MVT of the power clean—whether defined using MV or PV—was more reliable than

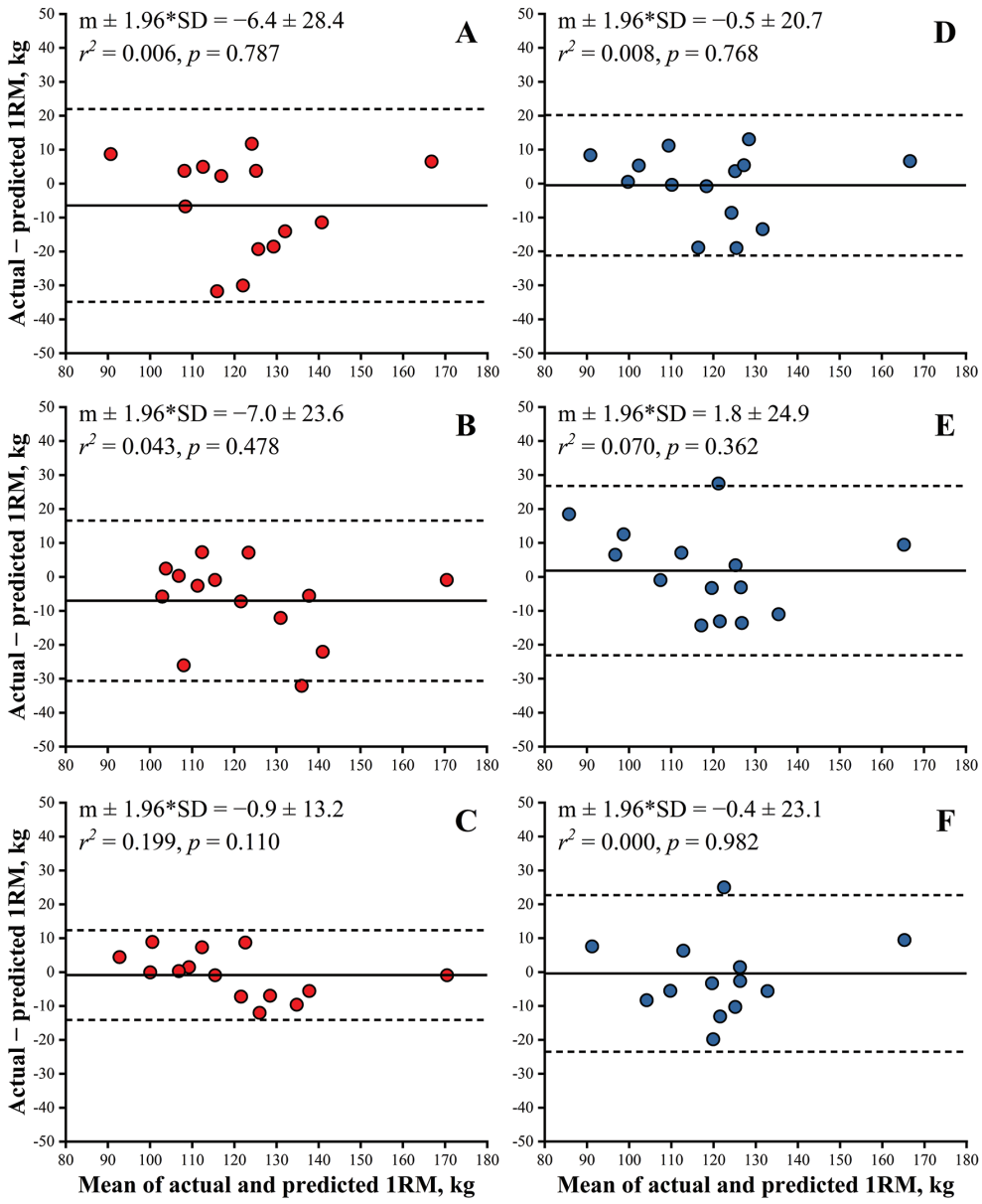


Figure 2. Bland–Altman plots showing the differences between the actual one-repetition maximum (1RM) and the 1RM estimated by the actual minimal velocity threshold (MVT) combined with the clean phase (A), jerk phase (B), and entire movement (C); optimal MVT combined with the clean phase (D), jerk phase (E), and entire movement (F). r^2 indicates goodness-of-fit.

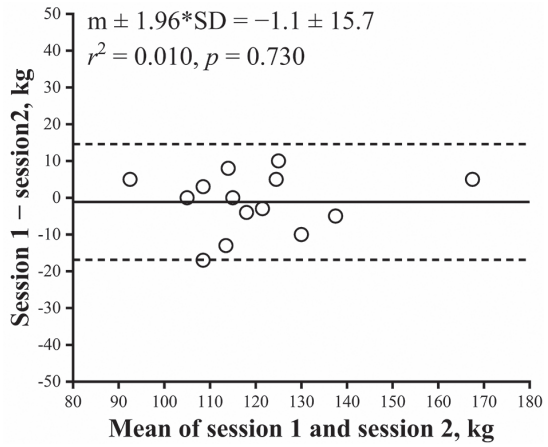


Figure 3. Bland–Altman plots showing the test-retest difference of the actual one-repetition maximum. r^2 indicates goodness-of-fit.

that of the back squat in competitive weightlifters. In traditional exercises such as the back squat, the presence of a "sticking point" and technical variability contribute to inconsistent actual MVT (Stone, et al., 2024). In contrast, Olympic-style lifts usually rely more on barbell inertia from the "2nd pull" to the "catch" making movement success more dependent on reaching a specific PV threshold. Unlike grinding lifts, the MVT in the clean and jerk specifically represents the peak velocity required to achieve sufficient barbell height for the lifter to effectively pull under and catch the bar. These features contribute to more stable actual MVTs in weightlifting movements. The present findings in the clean and jerk align with those of Thompson et al. (2021), as the actual MVT demonstrated low

within-participant CVs (5.70–6.16%). However, relatively low ICCs (0.46–0.51) suggest rank-order inconsistencies across sessions, which may reduce predictive accuracy when using the actual MVT to estimate 1RM, supporting the notion that using similar MVT value across athletes might yield more consistent predictions (Fitas, et al., 2024b; Pestaña-Melero, Haff, Rojas, Pérez-Castilla, & García-Ramos, 2017). In contrast, both 1RM load and PV at submaximal loads demonstrated strong reliability (ICC = 0.77–0.94, CV = 1.83–4.73%). As a result, the optimal MVT derived from the load–PV regression showed greater reliability (a higher 95% CI lower limit) than the actual MVT. These findings support the use of the optimal MVT during pre-competition warm-ups as a reliable marker to inform attempt selection in weightlifting. The actual MVT for the entire clean and jerk movement changed from 1.80 $m \cdot s^{-1}$ in the first session to 1.75 $m \cdot s^{-1}$ in the second session, whereas the optimal MVT changed from 1.79 $m \cdot s^{-1}$ to 1.81 $m \cdot s^{-1}$. Because the actual MVT in the first session was close to the optimal MVT (i.e., the MVT value that eliminates prediction error) in the second session, the actual MVT combined with the entire clean and jerk movement yielded the best prediction outcome in the current study. However, it must be acknowledged that the lower reliability of actual MVT may lead to more fluctuating 1RM estimations comparing with the optimal MVT as was the case for the clean and jerk phases when analyzed separately.

No proportional bias was detected (r^2 = 0.000–0.199, p=.110–0.982), indicating that the tendency of velocity-based and "gold standard" methods to overestimate or underestimate 1RM does not vary with athletes' performance. However, in weightlifting competitions, outcomes are often decided by less than five kg, and the observed random error (13.2–23.1 kg) among methods may still be too large to support precise attempt selection in a simulated or actual competition (Yan, Lan, Wu, & Hu, 2024). Given the frequent use of 1RM testing in weightlifters' training routines, determining competition attempts could be informed by a combination of the most recent 1RM performance, real-time subjective measures (e.g., readiness questionnaires), and real-time objective measures (e.g., changes in lifting velocity). Nevertheless, the feasibility and practical utility of this novel combined approach—incorporating velocity-based metrics—should be validated by future research in the clean and jerk, snatch, and other weightlifting exercises, as well as in simulated or official competitions.

Several limitations existed in this study. First, all tests were conducted during regular training sessions in the off-season. In competition, factors such as mental stress and weight reduction may influence lifting velocity and actual 1RM performance, warranting further investigation. Second, the study population was limited to adolescent athletes. Previous studies have suggested that adult competitive weightlifters may achieve more accurate 1RM predictions in the snatch due to their refined lifting techniques (Sandau, Chaabene, & Granacher, 2021). However, considering that Olympic-style lifts rely more on barbell inertia generated during the "second pull" to the "catch", a longer trunk length may reduce the reliability of the actual MVT in adult athletes (Sandau, et al., 2023). As there are currently no longitudinal studies tracking youth athletes into adulthood, nor cross-sectional studies comparing youth and adult athletes of similar performance levels, the present findings should be interpreted with caution when extrapolating to athletes of different age groups. Third, this study did not combine video analysis with linear position transducer data; thus, it was not possible to determine whether fluctuations in velocity were primarily due to technical errors or strength-related factors. Fourth, variations in lifting velocity during the jerk phase may also arise from different jerk techniques (e.g., split jerk *vs.* squat jerk). Specifically, including one squat jerker alongside thirteen split jerkers serves as a potential confounding variable due to their distinct biomechanics, displacement, and lifting velocity requirements. These factors collectively may have contributed to the variability observed in the accuracy of 1RM predictions.

In conclusion, the absolute errors from the test-retest of the actual 1RM were comparable to those of all velocity-based methods, except for the clean phase combined with the actual MVT, which showed larger errors. Among velocity-based methods, the load–PV relationship from the entire clean and jerk yielded the lowest absolute error when using the actual MVT, and the lowest raw error when using the optimal MVT. Although the actual MVT yielded the lowest absolute errors in this study, its lower reliability compared to the optimal MVT suggests that this result is likely incidental and unlikely to be consistent in practice, as reflected by the greater variability observed when the clean and jerk phases were analyzed separately. While random errors for velocity-based methods were large, they were similar to those of the actual 1RM test-retest. As neither approach demonstrated high accuracy in isolation, future research should assess whether combining them can enhance 1RM prediction. In practice, although PV measurement alone is not a highly precise predictor of clean and jerk performance, monitoring PV during warm-up sets may provide valuable complementary information for selecting opening attempts in weightlifting competitions. For instance, observing a 0.1 $m \cdot s^{-1}$ drop in PV during a 90% 1RM warm-up could tactically dictate reducing the opening attempt.

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