©Journal of Sports Science and Medicine (2026) **25,** 130-137
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2026.130

Research article

Evaluating Velocity-Based Approaches for Predicting One-Repetition Maximum in The Snatch

Yaxu Mao [1,†], Zongwei Chen [2,3,†], Daniel Marcos-Frutos [2], Zhaoqian Li [2], Shuheng Huang [1], Yong Mao [1]✉ and Amador García-Ramos [2,4]

[1] School of Physical Education and Sports Science, Jimei University, Xiamen, China; [2] Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain; [3] School of Physical Education and Sports Science, South China Normal University, Guangzhou, China; [4] Department of Sports Sciences and Physical Conditioning, Faculty of Education, Universidad Católica de la Santísima Concepción, Concepción, Chile

† These authors contributed equally to this work

Abstract

This study examined the reliability and accuracy of various velocity-based methods for predicting the snatch one-repetition maximum (1RM), with the purpose of evaluating the potential of movement velocity as an objective indicator for attempt selection in competitive weightlifting. Fourteen competitive adolescent male weightlifters (age: 15.9 ± 0.9 years; training experience: 5.1 ± 0.9 years) completed two testing sessions, each involving an incremental loading test with attempts at 50%, 70%, 80%, and 90% of their best snatch record from the past 30 days, followed by load increases until reaching their actual 1RM. Peak velocity (PV) was recorded for all lifts with a linear position transducer. The 1RM in the second session was predicted using the load-PV relationship derived from four loads, combined with either the actual or optimal minimal velocity threshold (MVT) obtained in the first session. Additionally, 1RM was estimated from PV recorded at single loads (50%, 70%, 80%, and 90% 1RM), using the individual %1RM-PV relationship established during the first session. Acceptable between-sessions reliability was observed for the actual 1RM, PV tested at single loads (50 - 90% 1RM), actual MVT, and optimal MVT (intraclass correlation coefficient = 0.76 - 0.90, coefficient of variation = 1.82 - 3.31%). The actual MVT, optimal MVT and individual %1RM-PV relationship using 80% and 90% 1RM yielded acceptable and lower absolute errors (2.6 - 4.1 kg) compared to individual %1RM-PV relationship using 50% and 70% 1RM (6.2 - 9.9 kg). However, these methods exhibited proportional bias ($p = 0.002 - 0.018$). Furthermore, heteroscedasticity was observed for the actual MVT and 90% 1RM methods ($p = 0.022 - 0.026$). These results suggest that recording PV during warm-up sets prior to competition may serve as a complementary variable to support and refine opener selection in weightlifting competitions. However, weightlifting coaches should use this approach with caution, as it may not provide accurate snatch performance predictions for all athletes.

Key words: Lifting velocity, velocity-based training, weightlifting, Olympic lifting.

Introduction

Competitive weightlifting, as an Olympic sport, is becoming increasingly popular worldwide (Storey and Smith, 2012). In competition, athletes aim to lift the heaviest weight in snatch, clean & jerk, or their combined total within a bodyweight category (Sandau et al., 2022b). 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 et al., 2012). Coaches typically choose a near-maximal load for the opener (i.e., first attempt in the weightlifting competition) based on previous training performance, competition-day readiness, and rival attempts, a decision that is largely subjective and based on the coaches' experience. An opener set too heavy risks a failed attempt, while setting the opener too light may result in a missed opportunity to challenge a heavier load. This decision is challenging, as 1RM performance can be influenced by various factors such as mental stress and weight cutting (Kwan and Helms, 2022; Storey et al., 2016; Williams et al., 2017). Therefore, accurately predicting 1RM is crucial to optimizing opener selection in weightlifting competitions.

Velocity-based methods have gained popularity as an alternative to traditional 1RM testing, particularly in common resistance exercises such as the bench press (Janićijević et al., 2021), back squat (Chen et al., 2025a), and deadlift (Janićijević et al., 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 a 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 subjects in prior studies (i.e., general MVT) has been used (García-Ramos, 2025). 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 optimal MVT provides more accurate 1RM predictions than traditional (actual and general) MVTs in both the bench press (García-Ramos, 2023a) and back squat (Chen et al., 2025a; Fitas et al., 2024). When applied to weightlifting exercises, Haff et al. (2020) reported that the actual MVT failed to accurately predict the power clean 1RM in weightlifting enthusiasts. However, no study has examined whether using the optimal MVT could improve the accuracy of 1RM estimation in weightlifting exercises. If confirmed, this approach could provide weightlifting coaches with objective data to guide attempt selection in competition.

The accuracy of 1RM prediction may depend on the reliability of the MVT used in the estimation process (Chen et

Received: 04 August 2025 / Accepted: 27 November 2025 / Published (online): 01 March 2026

al., 2025a). Thompson et al. (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., 2025a; Fitas et al., 2024; 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., 2025a; Fitas et al., 2024; García-Ramos, 2023a; Janićijević et al., 2024; Miras-Moreno and García-Ramos, 2024). Therefore, whether the optimal MVT can demonstrate higher reliability than the actual MVT in weightlifting exercises, and whether it can provide more accurate 1RM predictions, warrants further investigation. On the other hand, the reliability of the individual %1RM-velocity relationship has been extensively investigated in traditional exercises (Banyard et al., 2018; Chen et al., 2025b; Thompson et al., 2021). Since competitive weightlifters routinely test their 1RM as a direct measure of performance and exhibit superior movement proficiency (Sandau and Granacher, 2022a), testing single loads and applying the individual %1RM-velocity relationship from a previous session may offer comparable - or even greater - predictive accuracy than relying on actual or optimal MVTs. Although the individual %1RM-velocity relationship has long been proposed as a method to regulate training loads (Thompson et al., 2025; Weakley et al., 2021), its accuracy in predicting 1RM has yet to be validated in both weightlifting and conventional exercises.

To address the gaps in previous research, this study had two main objectives. The first objective was to examine the between-sessions reliability of the actual MVT, optimal MVT, and peak velocity (PV) associated with 50%, 70%, 80%, and 90% 1RM of the snatch. We hypothesized that the between-sessions reliability of the optimal MVT and PVs associated with submaximal loads would be higher than that of the actual MVT (Chen et al., 2025a). The second objective was to evaluate the accuracy of different velocity-based methods for predicting snatch 1RM in a follow-up session: (i) using the load-PV relationship from four loads combined with either the actual or optimal MVT, and (ii) estimating 1RM from PV recorded at single loads (50%, 70%, 80%, or 90% 1RM) using the individual %1RM-PV relationship established previously. We hypothesized that the individual %1RM-PV relationship using heavier loads (e.g., 80% and 90% 1RM) and the optimal MVT method would provide more accurate 1RM predictions than the actual MVT method and the individual %1RM-PV relationship using lower loads (e.g., 50% and 70% 1RM) (Chen et al., 2025a; Thompson et al., 2021).

Methods

Design

A repeated-measures design was used to assess the reliability and accuracy of different velocity-based methods for predicting snatch 1RM. Participants completed two testing sessions separated by one week. Each session began with lifts at 50%, 70%, 80%, and 90% of their best snatch performance from the previous 30 days, followed by progressive load increases until their 1RM for that day was determined. Between-sessions reliability was assessed for actual MVT, optimal MVT, and PV at 50%, 70%, 80%, and 90% 1RM. To evaluate the accuracy of 1RM prediction, actual MVT, optimal MVT, and the individual %1RM-PV relationship - all derived from session one - were used to predict 1RM in session two. All testing was conducted at 2:30 p.m. during participants' regular training sessions under consistent environmental conditions (~20°C, ~65% humidity).

Participants

Considering an effect size of f = 0.25, an α error probability of 0.05, a power of 0.80, 1 group, 6 measurements, and assuming a correlation among repeated measures of 0.75, the sample size calculation indicated that at least 10 participants are required for detecting the postulated effects (G*Power software, version 3.1.9.6) (Miras-Moreno et al., 2024). Fourteen male competitive adolescent weightlifters (age: 15.9 ± 0.9 years; body height: 170.0 ± 6.2 cm; body mass: 67.6 ± 9.3 kg; best snatch record from the past 30 days: 103.4 ± 15.1 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. Testing was conducted only when participants, assessed on a readiness scale from 1 (poor) to 5 (well), reported a relaxed state (> 3). No participant required rescheduling of testing due to insufficient readiness. 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 (IRB approval: JMU202411088).

Procedures

Each testing session began with a 10-minute warm-up, which was part of the participants' daily pre-training routine and included dynamic stretching for the upper and lower limbs, as well as weightlifting technique drills with an empty barbell. After a 3-minute rest, participants commenced the incremental load testing protocol. The protocol consisted of three lifts at 50% (51.5 ± 7.6 kg), two lifts at 70% (72.1 ± 10.6 kg), one lift at 80% (82.7 ± 12.1 kg) and one lift at 90% (93.1 ± 13.7 kg) of their previous snatch 1RM record. The selection of testing loads was based on the recommendations of García-Ramos (2023c), who suggested using a lightest load within 40 - 50% 1RM and a heaviest load around 90% 1RM, complemented with appropriate intermediate loads to ensure a representative load-velocity relationship. The load was then progressively increased in 1 to 5 kg increments until participants achieved their actual 1RM, with a maximum of 5 attempts allowed. Most participants reached their 1RM within 2 - 4 attempts. Consistent with their regular training routine, participants rested approximately 1 minute between repetitions and 3 minutes between load increases. The fastest PV for each load was included in the data analysis (Haff et al., 2020). It is important to note that mean velocity (MV) is not suitable for monitoring the snatch, as the exercise involves two distinct ascending phases. The execution standards for the snatch in this study were consistent with the International Weightlifting Federation rules.

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; sampling rate = 100 Hz), 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.

For each load, only the fastest repetition 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 snatch and their associated PVs were used to create a linear regression model, determining the load-axis intercept and slope of the load-PV relationship. The optimal MVT was then calculated by solving for velocity using the actual 1RM load in the load-PV equation: optimal MVT = (actual 1RM − load intercept)/slope (Chen et al., 2025a; García-Ramos, 2023a; Miras-Moreno and García-Ramos 2024). Similarly, the individual %1RM-PV relationship was established using the relative load to the actual 1RM obtained in that session.

In the second session, a new load-PV relationship was developed using the same procedure. The 1RM for the second session was predicted by applying the MVTs from the first session. Additionally, each absolute load (50%, 70%, 80% and 90% 1RM) and corresponding PV from the second session were individually applied to the individual %1RM-PV relationship from the first session to estimate the 1RM of the second session (Sánchez-Medina et al., 2017). Specifically, the PV corresponding to an absolute testing load from the second session was substituted into the %1RM–PV relationship equation developed in the first session to determine the estimated %1RM for that absolute load. The 1RM was then calculated using the equation: estimated 1RM = absolute load / estimated %1RM. For example, if 60 kg was lifted at a PV of 2.6 m/s, and 2.6 m/s corresponded to 60% 1RM from session 1, then the estimated 1RM would be calculated as 60 / 0.6 = 100 kg.

Statistical analyses

Descriptive data were assessed for normal distribution using Shapiro-Wilk test and are presented as means and SD (Normal distribution) or medians and IQR (Non-normal distribution). Paired samples *t* tests, Cohen's d effect size (ES), intraclass correlation coefficient (ICC, model 3.1), and within-subjects coefficient of variation (CV) were used to investigate the between-session reliability of the basic data (actual 1RM, PVs corresponding to different testing loads, actual MVT, and optimal MVT) (Hopkins, 2015). The goodness-of-fit of both the average and individualised load-PV and %1RM-PV relationships were assessed through the coefficient of determination (r^2). A Friedman test with Dunn-Bonferroni post hoc corrections was applied to absolute errors between the actual and predicted 1RMs. The validity of predicted 1RMs with respect to the actual 1RM was examined through the Bland-Altman analysis. The magnitude of ES was interpreted as trivial (< 0.20), small (0.20 - 0.59), moderate (0.60 - 1.19), large (1.20 - 2.00), and very large (> 2.00) (Hopkins et al., 2009). Acceptable reliability was determined as an ICC > 0.7 and CV < 10% (Miras-Moreno et al., 2023). Proportional bias or heteroscedasticity was considered present when a significant linear regression was observed between the mean of the predicted and actual 1RM and the raw error or absolute error, respectively (Bland et al., 1999). Statistical analyses were performed using SPSS software (version 27.0, SPSS Ins., Chicago). Alpha was set at 0.05. Additionally, an exploratory supplementary analysis was conducted after completing the main analyses, in which individual data points with large prediction errors (>10 kg; n = 4) were removed to examine the CVs for the actual and optimal MVTs. The results of this analysis are presented in the Discussion section.

Results

Non-significant ($p \geq 0.219$) and trivial to small (ES ≤ 0.23) differences were observed for basic variables between sessions (Table 1). The snatch 1RM demonstrated high between-sessions reliability (ICC = 0.98, CV = 2.16%). Notably, all PVs and MVTs exhibited acceptable between-sessions reliability (ICC = 0.76 - 0.90, CV = 1.82 - 3.31%).

Figure 1 illustrates the average load-PV and %1RM-PV relationships for both sessions. The individualized load-PV and %1RM-PV relationships, modeled using linear regression, exhibited a near perfect goodness-of-fit across the first (r^2 = 0.968 ± 0.027 [range from 0.915 to 0.999]) and second (r^2 = 0.960 ± 0.052 [range from 0.857 to 1.000]) sessions.

Table 1. Between-sessions reliability of the basic data.

Variable	Session 1	Session 2	*p*	ES	ICC (95%CI)	CV% (95%CI)
1RM, kg	101.1 ± 12.7	101.8 ± 13.3	0.452	0.05	0.98 (0.93, 0.99)	2.16 (1.57, 3.48)
50%1RM, $m{\cdot}s^{-1}$	2.67 ± 0.13	2.68 ± 0.19	0.830	0.04	0.76 (0.39, 0.91)	3.21 (2.33, 5.18)
70%1RM, $m{\cdot}s^{-1}$	2.37 ± 0.12	2.39 ± 0.12	0.436	0.15	0.77 (0.43, 0.92)	2.57 (1.86, 4.14)
80%1RM, $m{\cdot}s^{-1}$	2.17 ± 0.11	2.18 ± 0.11	0.407	0.11	0.90 (0.71, 0.97)	1.82 (1.32, 2.93)
90%1RM, $m{\cdot}s^{-1}$	2.02 ± 0.11	2.05 ± 0.12	0.219	0.23	0.80 (0.49, 0.93)	2.73 (1.98, 4.40)
Actual MVT, $m{\cdot}s^{-1}$	1.92 ± 0.13	1.93 ± 0.11	0.796	0.04	0.85 (0.59, 0.95)	2.61 (1.89, 4.21)
Optimal MVT, $m{\cdot}s^{-1}$	1.90 ± 0.14	1.91 ± 0.11	0.662	0.09	0.77 (0.42, 0.92)	3.31 (2.40, 5.34)

Data are presented as means ± SD. 1RM, one-repetition maximum; 95%CI, 95% confidence intervals; CV, within-subjects coefficient of variation; ES, Cohen's d effect size; ICC, intraclass correlation coefficient; MVT, minimal velocity threshold; 50 - 90%1RM, peak velocities corresponding to 50 - 90% of the participants' best snatch 1RM record.

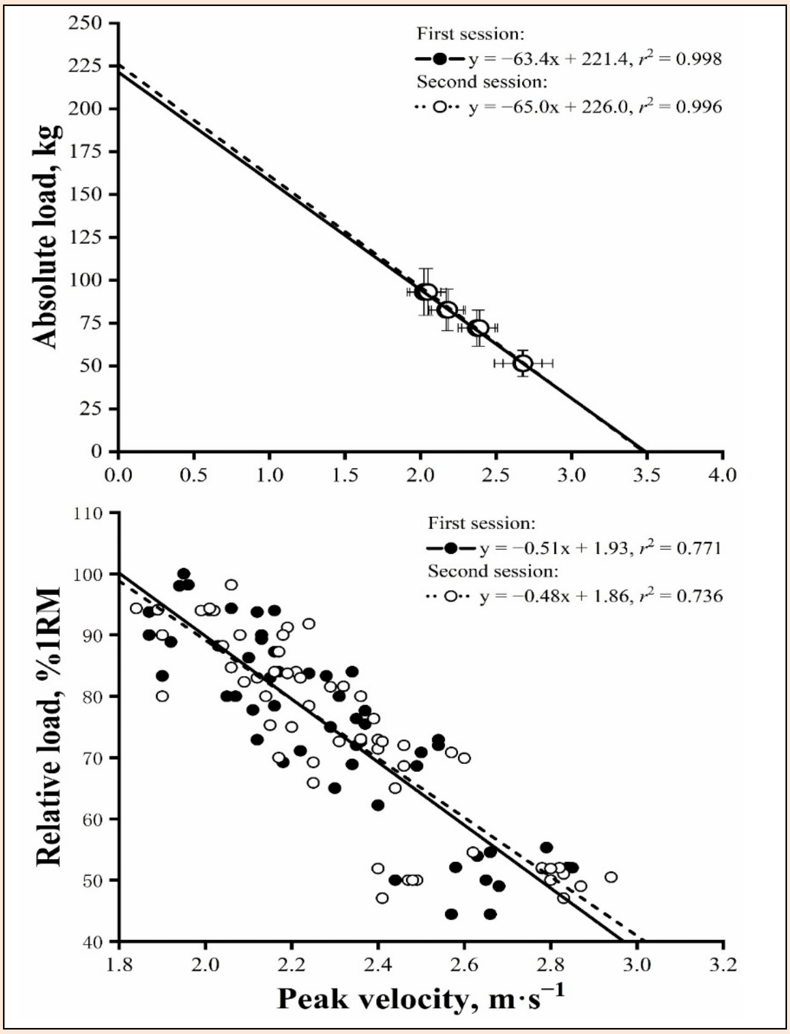

Figure 1. Averaged across the participants' relationships between: absolute load and peak velocity (upper-panel), and relative load and peak velocity (lower-panel). The equation and goodness-of-fit (r^2) are shown. 1RM, 1-repetition maximum.

Figure 2 illustrates significant differences in 1RM prediction accuracy (Q = 13.5, p = 0.019). Post hoc comparisons showed that the individualized %1RM-V relationship using 80% 1RM was more accurate than using 50% 1RM (p = 0.018), while other methods showed no differences ($p \geq 0.129$).

No systematic bias was detected for any method (p = 0.111 - 0.838, ES = -0.03 to 0.32); however, all methods showed large random errors (11.9 - 29.1 kg). Proportional bias was found in the 1RM predictions using actual MVT, optimal MVT, 80% 1RM, and 90% 1RM (p = 0.002 - 0.018), while heteroscedasticity was observed in the predictions using actual MVT and 90% 1RM (p = 0.022 - 0.026) (Figure 3, Table 2).

Discussion

This study assessed the reliability and accuracy of different velocity-based methods for predicting snatch 1RM in adolescent competitive weightlifters. The main findings suggest that the actual MVT, optimal MVT, and PVs at submaximal loads demonstrated acceptable between-sessions reliability. Predicted 1RMs showed no systematic error from actual 1RM. Absolute errors were below 5 kg when using actual MVT, optimal MVT, and the %1RM-PV relationship using heavier loads (80% and 90% 1RM). However, these methods exhibited proportional bias, driven by a tendency to overestimate in stronger individuals and underestimate in weaker ones. Furthermore, heteroscedasticity was observed for the actual MVT and 90% 1RM methods, indicating that prediction errors tended to increase as athletes' performance increased.

Previous studies have reported that the optimal MVT using MV is more reliable than the actual MVT in bench press (ICC = 0.56 - 0.73 *vs.* 0.34) (García-Ramos, 2023a) and back squat (CV = 7.1 - 9.3% *vs.* 16.6 - 17.0%) (Chen et al., 2025a). However, our results did not confirm this for the snatch, as the optimal MVT (CV = 3.31%) showed similar reliability compared to the actual MVT (CV = 2.61%) using PVs. The differences in reliability between both types of MVT were reduced after excluding from the analysis individuals with large prediction errors (> 10 kg) (CV = 1.97% for optimal MVT and 2.30% for actual MVT). Notably, PVs attained at single submaximal loads always demonstrated acceptable reliability (ICC = 0.76 - 0.90, CV = 1.82 - 3.21%). Unlike traditional exercises, the transition from the "2nd pull" to "catch" in the snatch relies heavily on inertia, making success at 1RM dependent on a specific PV threshold among other factors. This aligns with Thompson et al. (Thompson et al., 2021), who found greater actual MVT reliability in power clean than in squat among competitive weightlifters (CV = 8.1% *vs.* 27.8%). Although weightlifting exercises are typically considered ballistic movements, they differ from exercises like the bench press throw or squat jump, where maximal effort can be exerted even with light loads (García-Ramos, 2023c). In weightlifting, catching the barbell limits true maximal intent at lower loads (Sandau et al., 2021). In this study, 50% 1RM was selected as the initial load to establish the load-PV relationship, with its PV showing high reliability (ICC = 0.76, CV = 3.21%), and near-perfect linearity of the load-PV relationship (r^2 = 0.968 ± 0.027 in session one, 0.960 ± 0.052 in session two), supporting its suitability for determining the optimal MVT in the snatch. However, as shown in the lower panel of Figure 1, the range of PV values observed around 50% 1RM is highly variable between sessions, suggesting that the %1RM-PV relationship may be more reliable when using heavier loads as the lightest load.

Contrary to our hypothesis, actual and optimal MVTs showed comparable accuracy in predicting snatch 1RM, and given their low absolute errors, either could be used for estimation. When using the %1RM-PV relationship, absolute errors increased as the experimental points were farther from 1RM, with errors of 9.9 kg at 50% 1RM and 6.2 kg at 70% 1RM, suggesting these loads are unsuitable for snatch 1RM prediction. This aligns with García-Ramos's perspective that prediction errors increase when experimental points are farther from the target value (García-Ramos, 2023c). Interestingly, predictions using the 90% 1RM were not more accurate than using the 80% 1RM, differing from traditional exercises where accuracy improves with heavier testing loads (García-Ramos, 2023c). A likely explanation is that although 90% 1RM is closer to 1RM, it exhibited lower reliability compared to the 80% 1RM (ICC = 0.80 *vs.* 0.90; CV = 2.73% *vs.* 1.82%, respectively). Given the small absolute errors of the actual MVT, the optimal MVT and the %1RM-PV relationship using the 80 to 90% 1RM, any of these methods could serve as objective tools to assist coaches in selecting competition attempts after warm-up. However, while this approach introduces objective data to weightlifting, final decisions should not rely solely on velocity-based estimates. Snatch performance is influenced by additional factors such as barbell horizontal displacement, drop height, and the lifter's velocity during the turnover phase (Chavda et al., 2021; Liu et al., 2018; Mastalerz et al., 2019; Nagao et al., 2019; Nagao et al., 2023).

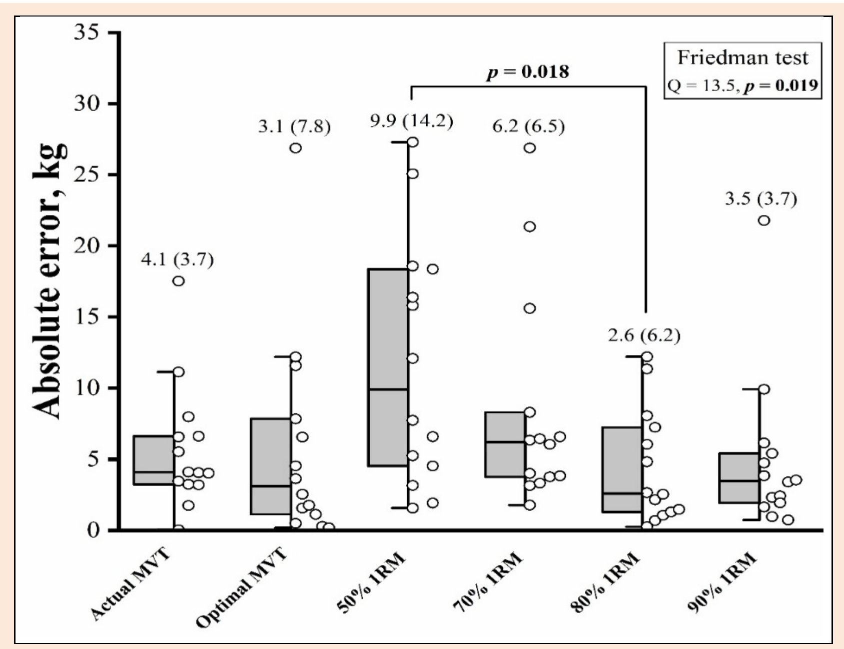

Figure 2. Box plots with median, interquartile range, and individual data points. 1RM indicates one-repetition maximum; 50 - 90% 1RM, 1RM prediction methods based on the relative load-peak velocity relationship using data from 50 - 90% 1RM; MVT, minimal velocity threshold. Bold values indicate *p* < 0.05.

Table 2. Systematic bias, random error, proportional bias, and heteroscedasticity for one-repetition maximum (1RM) estimation methods.

Method	m ± 1.96SD, kg	Systematic Bias		Proportional Bias		Heteroscedasticity	
		p	ES	r^2	*p*	r^2	*p*
Actual MVT	−0.4 ± 14.3	0.838	−0.02	0.385	**0.018***	0.351	**0.026***
Optimal MVT	1.2 ± 18.3	0.646	0.07	0.504	**0.004***	0.181	0.130
50% 1RM	1.2 ± 29.1	0.765	0.08	0.150	0.171	0.074	0.345
70% 1RM	4.8 ± 20.4	0.111	0.32	0.093	0.290	0.009	0.746
80% 1RM	−0.5 ± 11.9	0.778	−0.03	0.581	**0.002***	0.060	0.398
90% 1RM	2.1 ± 14.0	0.294	0.13	0.456	**0.008***	0.364	**0.022***

ES, Cohen'd effect size; MVT, minimal velocity threshold; r^2, goodness-of-fit.

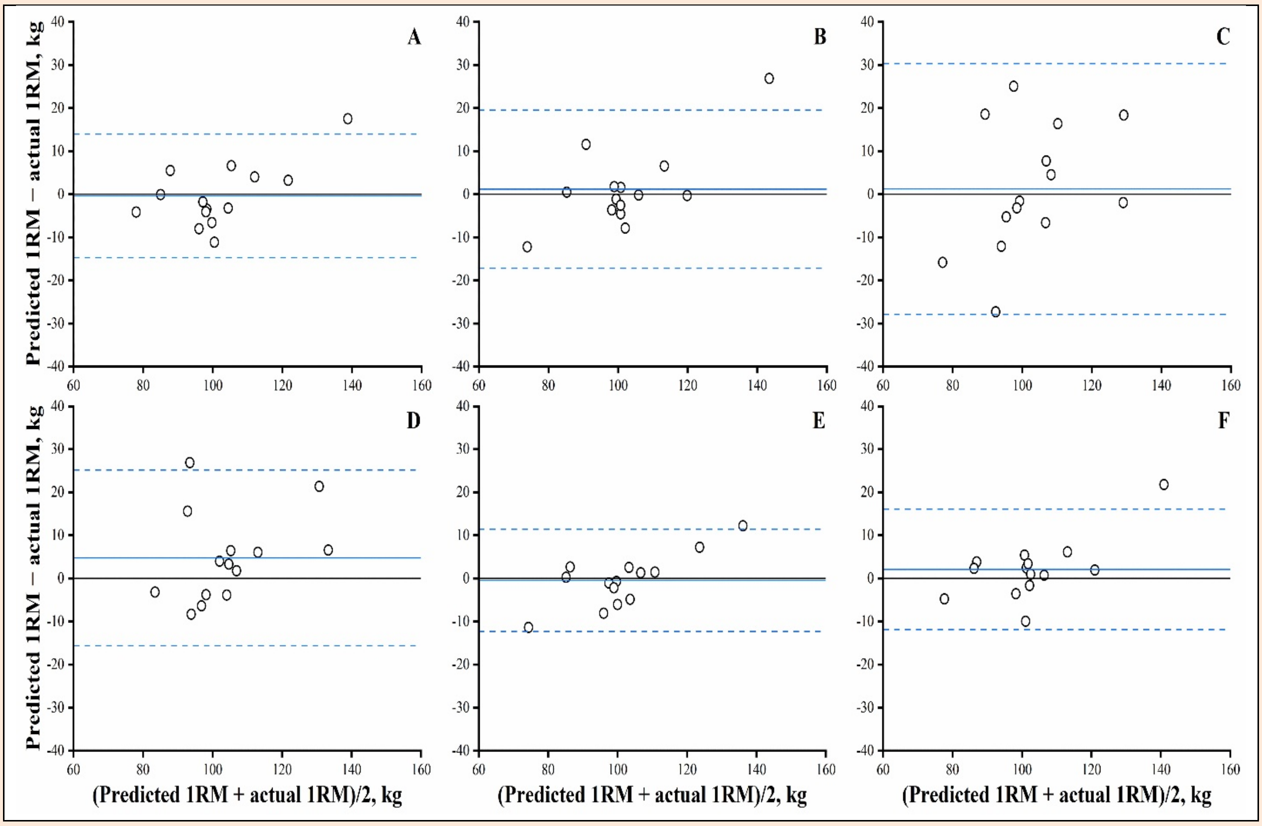

Figure 3. Bland-Altman plots for actual minimal velocity threshold (MVT, A), optimal MVT (B), and relative load-peak velocity relationship using 50% (C), 70% (D), 80% (E), and 90% (F) of one-repetition maximum (1RM). The plots display data points, the zero line (black solid line), the systematic bias (blue solid line), and the random error (blue dashed lines).

Although the raw and absolute errors of 1RM predictions were within acceptable ranges for all methods except the %1RM-PV relationship using 50% and 70% 1RM, the presence of proportional bias and heteroscedasticity poses challenges for practical application. Competitive weightlifting require extremely high accuracy as performance differences among athletes in the same weight category are often minimal (Yan et al., 2024). This study found that the accuracy of velocity-based methods for predicting snatch 1RM in youth competitive weightlifters is questionable due to the presence of proportional bias - characterized by a tendency to overestimate 1RM in stronger athletes and underestimate it in weaker ones - when using the actual MVT, optimal MVT, 80% 1RM, and 90% 1RM methods. Additionally, heteroscedasticity was observed for the actual MVT and 90% 1RM methods, indicating that prediction errors tended to increase with athletes' performance levels. 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 snatch and other weightlifting exercises. Future research could compare the success rates of attempts selected using subjective, previous 1RM-based, and velocity-based methods, providing more practical guidance for coaches.

Although this study provides novel and practical insights for weightlifting competitors, it is not without limitations. First, all tests were conducted during the off-season. In competition, factors such as mental stress and weight reduction may influence lifting velocity, warranting further investigation. Second, the study population was limited to adolescent male athletes. Previous research suggests that females exhibit lower lifting velocities at lighter relative loads compared to males, while velocities at heavier loads are similar (Nieto-Acevedo et al., 2023). This difference could influence the slope of the load-PV relationship and, in turn, the optimal MVT value. Third, the load-PV and %1RM-PV relationships were established under progressive fatigue, as rest intervals (1 minute between repetitions and 3 minutes between loads) may not have allowed full recovery. While consistent with the athletes' training routines, this could have affected lifting velocity and model accuracy, making the results more reflective of training rather than competition 1RM performance.

Conclusion

Our findings revealed that the actual MVT, optimal MVT, and the individual %1RM-PV relationship using approximately the 80% and 90% 1RM may accurately predict snatch 1RM. Among these methods, the %1RM-PV relationship using 80% 1RM may be the most practical for regular monitoring, as it requires lighter loads and less testing time. However, large random errors, proportional bias, and heteroscedasticity limited the ability of these methods to accurately predict performance across all athletes. Nevertheless, current findings suggest that recording PV during warm-up sets prior to competition could serve as a complementary variable to support and refine opener selection in weightlifting competitions.

Acknowledgements

This project was funded by the National Social Science Fund in China [grant number 21BTY120]. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The dataset supporting the conclusions of this article is included within the article and its additional file. The authors would like to thank Jingxuan Gao and Qingquan Wang for their valuable assistance in data collection. The authors would like to thank all the athletes who selflessly participated in the study.

References

Banyard, H. G., Nosaka, K., Vernon, A. D. and Haff, G. G. (2018) The reliability of individualized load-velocity profiles. *International Journal of Sports Physiology and Performance* **13**(**6**), 763-769. https://doi.org/10.1123/ijspp.2017-0610

Bland, J. M. and Altman, D. G. (1999) Measuring agreement in method comparison studies. *Statistical Methods in Medical Research* **8**(**2**), 135-160. https://doi.org/10.1177/096228029900800204

Chavda, S., Hill, M., Martin, S., Swisher, A., Haff, G. G. and Turner, A. N. (2021) Weightlifting: An applied method of technical analysis. *Strength and Conditioning Journal* **43**(**4**), 32-42. https://doi.org/10.1519/SSC.0000000000000614

Chen, Z., Xiao, F., Mao, Y., Zhang, X. and García-Ramos, A. (2025a) An efficient and accurate approach for estimating the free-weight back squat 1-repetition maximum based on the 2-point method and optimal minimal velocity threshold. *Journal of Strength and Conditioning Research* **39**(**4**), e530-e537. https://doi.org/10.1519/jsc.0000000000005040

Chen, Z., Zhang, X. and García-Ramos, A. (2025b) Evaluating the field 2-point method for the relative load-velocity relationship monitoring in free-weight back squats. *Journal of Human Kinetics* **97**, 183-195. https://doi.org/10.5114/jhk/193975

Fitas, A., Gomes, M., Santos, P., Gonçalves, A. D., Pezarat-Correia, P. and Mendonca, G. V. (2024) Optimal minimum-velocity threshold to predict one-repetition maximum for the back squat. *International Journal of Sports Medicine* **45**(**12**), 923-929. https://doi.org/10.1055/a-2335-4143

García-Ramos, A. (2023a) Optimal minimum velocity threshold to estimate the 1-repetition maximum: The case of the smith machine bench press exercise. *International Journal of Sports Physiology and Performance* **18**(**4**), 393-401. https://doi.org/10.1123/ijspp.2022-0355

García-Ramos, A. (2023b) Resistance training intensity prescription methods based on lifting velocity monitoring. *International Journal of Sports Medicine* **45**(**4**), 257-266. https://doi.org/10.1055/a-2158-3848

García-Ramos, A. (2023c) Two-point method: Theoretical basis, methodological considerations, experimental support, and its application under field conditions. *International Journal of Sports Physiology and Performance* **18**(**10**), 1092-1100. https://doi.org/10.1123/ijspp.2023-0127

García-Ramos, A. (2025) *Velocity-based training: Prescribing and assessing the effects of resistance training* (1st Edition ed.). Routledge. https://doi.org/10.4324/9781003163596

Haff, G. G., García-Ramos, A. and James, L. P. (2020) Using velocity to predict the maximum dynamic strength in the power clean. *Sports* **8**(**9**), 129. https://doi.org/10.3390/sports8090129

Hopkins, W. G., Marshall, S. W., Batterham, A. M. and Hanin, J. (2009) Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise* **41**(**1**), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Hopkins, W. G. (2015) Spreadsheets for analysis of validity and reliability. *Sportscience* **19**, 36-42.

Janićijević, D., Jukic, I., Weakley, J. and García-Ramos, A. (2021) Bench press 1-repetition maximum estimation through the individualized load-velocity relationship: Comparison of different regression models and minimal velocity thresholds. *International Journal of Sports Physiology and Performance* **16**(**8**), 1074-1081. https://doi.org/10.1123/ijspp.2020-0312

Janićijević, D., Şentürk, D., Akyildiz, Z., Gu, Y. and García-Ramos, A. (2024) Hexagonal barbell deadlift one-repetition maximum estimation using velocity recordings. *International Journal of Sports Medicine* **45**(**11**), 844-850. https://doi.org/10.1055/a-2330-3001

Kwan, K. and Helms, E. (2022) Prevalence, magnitude, and methods of weight cutting used by world class powerlifters. *Journal of Strength and Conditioning Research* **36**(**4**), 998-1002. https://doi.org/10.1519/jsc.0000000000004199

Liu, G., Fekete, G., Yang, H., Ma, J., Sun, D., Mei, Q. and Gu, Y. (2018) Comparative 3-dimensional kinematic analysis of snatch technique between top-elite and sub-elite male weightlifters in 69-kg category. *Heliyon* **4**(**7**), e00658. https://doi.org/10.1016/j.heliyon.2018.e00658

Mastalerz, A., Szyszka, P., Grantham, W. and Sadowski, J. (2019) Biomechanical analysis of successful and unsuccessful snatch lifts in elite female weightlifters. *Journal of Human Kinetics* **68**, 69-79. https://doi.org/10.2478/hukin-2019-0057

Miras-Moreno, S., García-Ramos, A., Jukic, I. and Pérez-Castilla, A. (2023) Two-point method applied in field conditions: A feasible approach to assess the load-velocity relationship variables during the bench pull exercise. *Journal of Strength and Conditioning Research* **37**(**7**), 1367-1374. https://doi.org/10.1519/jsc.0000000000004405

Miras-Moreno, S. and García-Ramos, A. (2024) The effect of lifting straps on the prediction of the maximal neuromuscular capabilities and 1 repetition maximum during the prone bench pull exercise. *Journal of Strength and Conditioning Research* **38**(**11**), e638-e644.

Nagao, H., Kubo, Y., Tsuno, T., Kurosaka, S. and Muto, M. (2019) A biomechanical comparison of successful and unsuccessful snatch attempts among elite male weightlifters. *Sports* **7**(**6**), 151. https://doi.org/10.3390/sports7060151

Nagao, H., Huang, Z. and Kubo, Y. (2023) Biomechanical comparison of successful snatch and unsuccessful frontward barbell drop in world-class male weightlifters. *Sports Biomechanics* **22**(**9**), 1120-1135. https://doi.org/10.1080/14763141.2020.1787498

Nieto-Acevedo, R., Romero-Moraleda, B., Díaz-Lara, F. J., Rubia, A., González-García, J. and Mon-López, D. (2023) A systematic review and meta-analysis of the differences in mean propulsive velocity between men and women in different exercises. *Sports* **11**(**6**), 118. https://doi.org/10.3390/sports11060118

Sánchez-Medina, L., Pallarés, J. G., Pérez, C. E., Morán-Navarro, R. and González-Badillo, J. J. (2017) Estimation of relative load from bar velocity in the full back squat exercise. *Sports Medicine - International Open* **1**(**2**), E80-E88. https://doi.org/10.1055/s-0043-102933

Sandau, I., Chaabene, H. and Granacher, U. (2021) Predictive validity of the snatch pull force-velocity profile to determine the snatch one repetition-maximum in male and female elite weightlifters. *Journal of Functional Morphology and Kinesiology* **6**(**2**), 35. https://doi.org/10.3390/jfmk6020035

Sandau, I. and Granacher, U. (2022a) Long-term monitoring of training load, force-velocity profile, and performance in elite weightlifters: A case series with two male olympic athletes. *Journal of Strength and Conditioning Research* **36**(**12**), 3446-3455. https://doi.org/10.1519/jsc.0000000000004228

Sandau, I., Chaabene, H. and Granacher, U. (2022b) Validity and reliability of a snatch pull test to model the force-velocity relationship in male elite weightlifters. *Journal of Strength and Conditioning Research* **36**(**10**), 2808-2815. https://doi.org/10.1519/jsc.0000000000003949

Storey, A. and Smith, H. K. (2012) Unique aspects of competitive weightlifting: Performance, training and physiology. *Sports Medicine* **42**(**9**), 769-790. https://doi.org/10.1007/bf03262294

Storey, A. G., Birch, N. P., Fan, V. and Smith, H. K. (2016) Stress responses to short-term intensified and reduced training in competitive weightlifters. *Scandinavian Journal of Medicine and Science in Sports* **26**(**1**), 29-40. https://doi.org/10.1111/sms.12400

Thompson, S. W., Rogerson, D., Ruddock, A., Banyard, H. G. and Barnes, A. (2021) Pooled versus individualized load-velocity profiling in the free-weight back squat and power clean. *International Journal of Sports Physiology and Performance* **16**(**6**), 825-833. https://doi.org/10.1123/ijspp.2020-0534

Thompson, S. W., Fernandes, J., Dorrell, H., Greig, L. and Bishop, C. (2025) A coach's guide to velocity-based training: Definitions and diagnostics. *Strength and Conditioning Journal* **47**(**2**), 230-244. https://doi.org/10.1519/ssc.0000000000000886

Todd, J. S., Shurley, J. P. and Todd, T. C. (2012) Thomas L. DeLorme and the science of progressive resistance exercise. *Journal of Strength and Conditioning Research* **26**(**11**), 2913-2923. https://doi.org/10.1519/JSC.0b013e31825adcb4

Weakley, J., Mann, B., Banyard, H., McLaren, H. S., Scott, T. and García-Ramos, A. (2021) Velocity-based training: From theory to application. *Strength and Conditioning Journal* **43**(**2**), 31-49. https://doi.org/10.1519/ssc.0000000000000560

Williams, B., Clarke, R., Aspe, R., Cole, M. and Hughes, J. (2017) Managing performance throughout periods of travel. *Strength and Conditioning Journal* **39**(**4**), 22-29. https://doi.org/10.1519/ssc.0000000000000317

Yan, W., Lan, P., Wu, C. and Hu, W. (2024) Foot kinematics of elite female 59 kg weightlifters in the 2018-2021 world championships. *Journal of Functional Morphology and Kinesiology* **9**(**4**), 207. https://doi.org/10.3390/jfmk9040207

Key points

- The actual MVT, optimal MVT, and PVs at submaximal loads showed acceptable between-session reliability.
- Predicted 1RMs showed no systematic error, with absolute errors below 5 kg when using actual MVT, optimal MVT, and the %1RM-PV relationship with 80% and 90% 1RM.
- Above methods showed proportional bias, and for actual MVT and 90% 1RM methods, prediction errors increased with athlete performance (heteroscedasticity).

AUTHOR BIOGRAPHY

Yaxu MAO
Employment
School of Physical Education and Sports Science, Jimei University, Xiamen, China.
Degree
Master
Research interests
Strength & conditioning and weightlifting
E-mail: myaxu2000@163.com

Zongwei CHEN
Employment
Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain and school of Physical Education and Sports Science, South China Normal University, Guangzhou, China.
Degree
Master
Research interests
Strength & conditioning and velocity-based training
E-mail: 2022021047@m.scnu.edu.cn

Daniel MARCOS-FRUTOS
Employment
Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain.
Degree
Master
Research interests
Strength & conditioning, weightlifting, nutrition, and velocity-based training
E-mail: danimarcos@ugr.es

Zhaoqian LI
Employment
Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain.
Degree
Master
Research interests
Strength & conditioning, velocity-based training, force-velocity relationship, and fatigue monitoring
E-mail: lzqf3ng@gmail.com

Shuheng HUANG
Employment
School of Physical Education and Sports Science, Jimei University, Xiamen, China.
Degree
Master
Research interests
Strength & conditioning and weightlifting
E-mail: hshwd@126.com

Yong MAO
Employment
School of Physical Education and Sports Science, Jimei University, Xiamen, China.
Degree
Professor; doctor
Research interests
Strength & conditioning
E-mail: 202061000017@jmu.edu.cn

Amador GARCÍA-RAMOS
Employment
Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain and Department of Sports Sciences and Physical Conditioning, Faculty of Education, Universidad Católica de la Santísima Concepción, Concepción, Chile.
Degree
Professor; doctor
Research interests
Velocity-based training
E-mail: amagr@ugr.es

✉ **Yong Mao**
School of Physical Education and Sports Science, Jimei University, Xiamen, China