A COMPARISON OF THREE LOAD-VELOCITY BASED METHODS TO ESTIMATE MAXIMUM OVERHEAD PRESS PERFORMANCE IN WEIGHTLIFTERS

Running Title: Load-velocity methods to predict overhead press 1RM

Authors: Marcos A Soriano[1,2], Ester Jiménez-Ormeño[1,2], G Gregory Haff[3,4], Paul Comfort[3,4], Verónica Giráldez-Costas[1,2], Carlos Ruiz-Moreno[1,2], Amador García-Ramos[1,5,6].

Institutional Affiliations:

[1]*Strength Training and Neuromuscular Performance (STreNgthP) Research Group, Camilo José Cela University, Madrid, Spain.*

[2]*Exercise Physiology Laboratory, Camilo José Cela University, Madrid, Spain.*

[3]*Centre for Exercise and Sports Science Research (CESSR), School of Medical and Health Sciences, Edith Cowan University, Joondalup 6027, Australia.*

[4]*University of Salford, Frederick Road Campus, Manchester, United kingdom.*

[5]*Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain.*

[6]*Department of Sports Sciences and Physical Conditioning, Faculty of Education, Universidad Católica de la Santísima Concepción, Concepción, Chile.*

Corresponding Author:

Marcos A Soriano. Strength Training and Neuromuscular Performance (STreNgthP) Research Group, Camilo José Cela University, Madrid, Spain. E-mail: masoriano1991@gmail.com, msoriano@ucjc.edu.

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ABSTRACT

This study aimed to evaluate whether lifting velocity can be used to estimate the overhead press one repetition maximum (1RM) and to explore the differences in the accuracy of the 1RM between three velocity-based methods. Twenty-seven weightlifters (16 men and 11 women) participated. The first session was used to test the overhead press 1RM. The second session consisted of an incremental loading test during the overhead press. The mean velocity was registered using a transducer attached to the barbell. A 1-way repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc corrections was applied to the absolute differences between the actual and predicted 1RMs. Raw differences with 95% limits of agreement and ordinary least-products regressions were used to test the concurrent validity of the 1RM prediction methods with respect to the actual 1RM. The ANOVA did not reveal significant differences for the absolute differences respect to the actual 1RM between the three 1RM prediction methods ($F = 3.2$, $p = 0.073$). The absolute errors were moderate for the Multiple-Point (6.1 ± 3.7%), Two-Point$_{45\text{-}75}$ (8.6 ± 6.2%), and Two-Point$_{45\text{-}90}$ methods (5.7 ± 4.0%). The validity analysis showed that all the 1RM prediction methods underestimated the actual 1RM (1.0 – 2.2 kg), but ordinary least-products regressions failed to show fixed or proportional bias. These results suggest that the Multiple-Point and Two-Point$_{45\text{-}90}$ velocity-based methods might be viable tools to predict the overhead press 1RM in weightlifters, but practitioners are encouraged to use the direct 1RM for a more accurate prescription of the training loads.

Key words: one-repetition maximum, strength, weightlifting, force-velocity relationship, two-point method

INTRODUCTION

Weightlifters are required to lift greater loads than their opponents during the snatch and the clean and jerk in order to determine the competition total (i.e. the sum of the two lifts) and the overall winner of the weightlifting competition [1]. The performance capabilities of competitive weightlifters appear to depend primarily on lower body strength [2–4]. For example, Stone et al. [2] reported that the back squat one repetition maximum (1RM) was almost perfectly correlated with snatch (r = 0.94) and clean (r = 0.95) performance in well-trained male weightlifters. Similarly, Carlock et al. [3] reported nearly perfect correlations between the back squat 1RM and snatch (r = 0.94) and clean and jerk (r = 0.95) performance in weightlifters from the United States senior and junior national teams. Additionally, researchers have demonstrated that the overhead press 1RM is strongly related to the split jerk 1RM performance (r = 0.90) [5]. Therefore, it seems that the maximum dynamic strength of the lower and upper body are both major contributors to weightlifting performance.

Since the maximum dynamic strength of both the upper and lower body are related to weightlifting performance, it seems evident that practitioners should evaluate the 1RM of the back squat and overhead press to monitor changes in performance and guide the process of training (i.e., programming training loads). However, the direct assessment of the 1RM may not always be practical (e.g. a large group of athletes, novice athletes with no experience under maximal loads), therefore, the use of alternative 1RM prediction methods such as the modelling of the load-velocity relationship has been proposed [6,7]. This modelling is based on a linear inverse relationship between force and velocity that has been tested in a variety of multi-joint tasks such as the back squat or seated press [8–11]. However, researchers have demonstrated that the accuracy and reliability of the 1RM prediction based on the load-velocity relationship is exercise specific and can also be affected by other factors, such as the training status (i.e. execution technique proficiency), testing conditions (i.e. smith machine vs. free weights), measurement devices (e.g. accelerometers, linear position transducers [LPT]) used, and procedures followed to determine the load-velocity relationships [11–14].

The load-velocity relationship has previously been used to predict the 1RM performance in various exercises with the back squat and bench press being two of the exercises that have received the most scientific attention [10,15,16]. For example, Banyard et al. [10] compared the free weight back squat 1RM with a predicted 1RM using linear regression equations derived from the load-velocity relationship of 5 (20, 40, 60, 80, 90% 1RM), 4 (20, 40, 60, 80% 1RM) and 3

(20, 40, 60% 1RM) loads in resistance trained men. Banyard et al. [10] concluded that none of the regression models were able to predict the actual back squat 1RM (~140 ± 27 kg) with acceptable precision and the errors increased with the reduction in the number of loads tested (standard error of estimate [SEE] = 10.6, 12.9 and 17.9 kg, respectively). However, Caven et al. [15] determined in trained females that the bench press and back squat 1RM (38.6 ± 7.5 and 86.5 ± 14.7 kg, respectively) can be accurately predicted from the load-velocity relationship obtained by modelling 8 loads (bench press: 40, 45, 55, 60, 70, 80, 85 and 90% 1RM, back squat = 20, 30, 45, 55, 65, 75, 85 and 90% 1RM) and only 2 loads (~40 and 90% 1RM for bench press and 20 and 90% 1RM for back squat) (absolute errors ~ 2.9 kg for bench press and 5.6 kg for back squat). In addition, it is important to note that the study of Banyard et al. [10] suggested that the number of loads tested is an important consideration when modelling the load-velocity relationship. In contrast, the results of Caven et al. [15] indicate that testing more loads might not increase the accuracy of the 1RM prediction when the additional loads are not located closer to the 1RM.

Reliability and accuracy are important attributes to take into account when analyzing neuromuscular tests in sports performance [17]. There is evidence that the direct 1RM test is highly reliable regardless of resistance training experience, exercise selection, part of the body assessed (upper vs. lower body), sex and age of subjects [18]. Furthermore, the 1RM test is considered the gold standard for assessing the maximum dynamic strength of the upper and lower limbs [10,16]. Although the load-velocity modelling for predicting the 1RM has been proposed as a viable alternative to the 1RM direct test, it has been criticized in the scientific literature given that its reliability and accuracy has mainly been tested in a Smith Machine [16]. The use of free weights could result in a reduced reliability and accuracy, however, researchers suggest that this is a more sport-oriented neuromuscular stimulus [16]. In contrast, Loturco et al. [19] compared the accuracy of the predicted bench press 1RM using the Smith machine and free weights and determined a high level of precision for both conditions with no significant statistical differences ($p > 0.05$).

To the authors knowledge, researchers have not used the load-velocity relationship to estimate the 1RM during the free-weight overhead press. It is plausible that the 1RM could be obtained with an acceptable precision during the overhead press because the available literature suggests that the load-velocity relationship could be a viable option to predict the 1RM in upper-body exercises such as the bench press [16,20]. The possibility of predicting the overhead press 1RM can be of practical importance to weightlifters since the overhead press 1RM has been related to the split jerk performance [5]. Furthermore, the 1RM prediction accuracy could be specific to the procedure used with traditional (i.e. 4 – 5 loads) and novel procedures such as the 2-point method (i.e. 2 loads) [21]. Therefore, the aim of this study was to evaluate whether lifting velocity provides valuable information to estimate the overhead press 1RM. A further aim of this study was to explore if there are differences in the accuracy of the 1RM between three velocity-based methods based on different load combinations. It is hypothesized that the load-velocity relationship modelling could be a viable option to accurately predict the free-weight overhead press 1RM, and no differences are expected in the accuracy of the 1RM prediction between the three velocity-based methods differing in the number of loads tested when they do not differ in the magnitude of the heaviest load considered for the load-velocity relationship modelling.

METHODS

Participants

Twenty-seven competitive weightlifters volunteered to participate in the present study (**Table 1**). Subjects were amateur competitors in regional and national tournaments in weightlifting. Furthermore, they were required to have ≥ 6 months of weightlifting experience and regularly (≥ 3 x week) performed weightlifting trainings. All subjects were experienced in performing the overhead press and their regular training included this exercise, along with other pressing exercises (e.g., push press, behind the neck snatch push press, seated press). All subjects provided written informed consent prior to participation, with ethical approval provided by the institutional review board. The study conformed to the principles of World Medical Association´s Declaration of Helsinki.

[Table 1]

Study design

A cross-sectional study was designed to determine the accuracy of three velocity-based methods differing in the loads used for the load-velocity relationship modelling to estimate the overhead press 1RM in competitive weightlifters. Subjects were tested in their own weightlifting room. Researchers attended the weightlifting room on two occasions separated by 72 to 96 hours. The first session was used to test the free-weight overhead press 1RM. Note that researchers have previously reported that test-retest reliability of the overhead press is high (ICC = 0.98) and variation is low (CV = 4.0%) [5]. Therefore, the 1RM test was performed only once by all subjects. In addition, after the 1RM test, subjects were familiarized with the incremental loading procedure using multiple individual repetitions with maximum intent against various loads during the overhead press. The second session consisted of an incremental loading test of three repetitions against five different loads (30, 45, 60, 75 and 90% 1RM) during the free-weight overhead press, performed with maximum intent. The mean velocity of the barbell was measured and registered using a validated LPT (Chronojump; Boscosystem, Barcelona, Spain) [13]. Three methods, which only differed in the loads used to determine the individualized load-velocity relationships, were employed to estimate the overhead press 1RM: (I) multiple-point – five loads (i.e., 30, 45, 60, 75, 90%), (II) two-point$_{45\text{-}75}$ – two loads (45 and 75% 1RM), and (III) two-point$_{45\text{-}90}$ – two loads (45 and 90%1RM). The mean velocity value of 0.24 $m \cdot s^{-1}$ for the overhead press [9], was used for all subjects and prediction methods to simplify the testing procedure based on previous recommendations [20]. Verbal encouragement was provided throughout all testing conditions and subjects were specifically instructed to perform all repetitions with maximum intent. Subjects were asked to replicate their fluid and food intake 24 hours before the day of testing, to avoid strenuous exercise for 48 hours before testing, and to maintain any existing supplementation regimen throughout the duration of the study.

Testing Procedures

1RM test. Subjects completed a warm-up protocol for the overhead press. Briefly, the general warm-up consisted of dynamic activation and exercise-specific drills. The dynamic activation included mobility exercises for the scapulohumeral complex that were performed using a PVC pipe. After that, subjects performed two sets of ten repetitions of exercises-specific drills (push-ups, pike push-ups, barbell mass only overhead press). Subsequently, one set of five repetitions was performed with a load that corresponded to 50% of self-estimated 1RM. After three minutes of rest, another set of five repetitions was performed with a load that corresponded to 60% of self-estimated 1RM. Thereafter, two sets of three repetitions were performed with loads that corresponded to 70% and 85%, respectively. Subjects had three to five minutes of rest between these sets. After the general and specific warm-up, subjects rested for five minutes before the start of the 1RM test. The 1RM test for the overhead press started from a near-maximal load (95% of self-estimated 1RM) and each successful attempt was followed by an increment of the load of 2.5-5.0% until the 1RM was reached, allowing a maximum of five

1RM attempts, in accordance with the NSCA guidelines [22]. Subjects rested from three to five minutes between attempts. In the overhead press, the lifter begins standing with the barbell resting in the front rack position using a prone grip of medium width with the elbows oriented approximately at 45 degrees to the floor. Then, the barbell was pressed upward throughout the full flexion of the shoulders and extension of the elbows to an overhead position while the trunk and the lower limbs provide stability. Subjects were placed between two jerk stands and were allowed to drop the barbell over them. All testing were performed using standardized Olympic barbells and plates (Powerkan Sports Equipment, Valladolid, Spain), lifting platforms and jerk stands. A 20 kg Olympic barbell was used for men, while a 15 kg Olympic barbell was used for women. However, when the light loads (30, 45 % 1RM) were lighter than these loads, a 15 kg barbell was adapted for men, while a 10 kg barbell was used for women. All the equipment and plates inventory allowed for a progression of loads as light as 1 kg.

Load-velocity test. The technical requirements of the overhead press, previously described, were strictly followed during the incremental loading test. Subjects completed a general warm-up which consisted of dynamic activation and exercise-specific drills. Then, subjects performed 1 set of 5 repetitions at 50% 1RM and 1 set of 3 repetitions at 75% 1RM separated by 3 minutes of rest. Subjects had 3 to 5 minutes of rest after the warm-up. Thereafter, subjects performed an incremental loading test of 3 repetitions for 5 loading conditions (30, 45, 60, 75 and 90% 1RM). All repetitions were performed in a cluster set configuration (i.e. rest was added inter-repetitions) to minimize fatigue and maintain external mechanical outputs [23]. Thirty, 60 and 90 seconds of rest were allowed for 30, 45 and 60% 1RM, respectively, while 2 to 3 minutes were allowed for 75 and 90% 1RM. A LPT was attached to the barbell's right side and the position-time data was sampled at a frequency of 1000 Hz. There was a mark drawn in the floor for the lifter's feet and another for the position of the LPT to assure barbell path consistency and vertical displacement. Participants received visual velocity performance feedback immediately after completing each repetition to encourage them to give maximal effort and increase the reliability of velocity recordings. Raw data were exported from the custom software v.2.0.2 (Chronojump; Boscosystem, Barcelona, Spain) and then analyzed in Microsoft Excel (Microsoft, Redmond, WA, USA). Only the repetition with the highest mean velocity recorded at each load was used for modelling of the load-velocity relationships. Note that mean velocity has been recommended over other velocity variables (e.g. mean propulsive velocity or peak velocity) for predicting the 1RM through the individual load-velocity relationship [20].

[Table 2]

Statistical analyses

Normality of data was determined using the Shapiro-Wilk's test. The inter-repetition reliability of the two highest mean velocity values for each load were analyzed by means of intraclass correlation coefficient (ICC; model 3.1), %coefficient variation (CV) and their associated 95% confidence intervals (CI) using a customized Excel spreadsheet [24]. Reliability was interpreted based on the lower bound of the ICC 95%CI following the guidelines provided by Koo et al. [25]: poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90). Additionally, a CV <15% was used as a criterion for the minimum acceptable reliability [26].

The descriptive data are presented through means and SDs. A one-way repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc corrections was applied to the absolute differences between the actual and predicted 1RMs. The scale used to categorize the magnitude of the absolute errors was low (<5.0%), moderate (5.0%–10%), and high (>10.0%) [14]. The validity of the 1RM prediction methods with respect to the actual 1RM was examined through paired samples t tests, Hedge's *g* effect size (ES), raw differences with 95% limits of agreement, Pearson correlation coefficient (r), and the heteroscedasticity of the errors (i.e., relationship of the raw differences between the actual and predicted 1RMs with their average value). Furthermore, ordinary least-products regressions and Bland-Altman analysis were also used to explore the concurrent validity of the predicted 1RMs [27–29]. The strength of the regressions was examined through the Pearson's product-moment correlation coefficients (R), while the intercept and slope with their 95% CI were used to assess fixed and proportional bias, respectively. If the 95% CI for the intercept did not include 0, then fixed bias was present. If the 95% CI for the slope did not include 1.0, then proportional bias was present. If fixed or proportional bias was present this meant that the method was either not reliable or could not be used to accurately predict the actual overhead press 1RM [27–29]. Qualitative interpretations of the *r* coefficients were defined as follows: trivial (0.00–0.09), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), and perfect (1.00) [30]. Heteroscedasticity of the errors was defined as a $r^2 > 0.10$ [17]. The magnitude of the ES was interpreted as follows: trivial (<0.20), small (0.20–0.59), moderate (0.60–1.19), large

(1.20–2.00), and very large (> 2.00) [30]. The ANOVA was performed using SPSS software (version 25.0; SPSS Inc, Chicago, IL) and the remaining analyses with Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Statistical significance was set at an alpha level of $\leq$0.05.

RESULTS

The characteristics of the different loads used for the load-velocity relationship modelling and the reliability of mean velocity outputs are presented in **Table 2**. There were no significant differences for the absolute differences respect to the actual 1RM between the three 1RM prediction methods (F = 3.2, p = 0.073) (**Figure 1**). The absolute errors were categorized as moderate for the Multiple-Point (3.5 ± 2.4 kg; 6.1 ± 3.7%), Two-$Point_{45-75}$ (4.9 ± 4.5 kg; 8.6 ± 6.2%), and Two-$Point_{45-90}$ methods (3.1 ± 2.0 kg; 5.7 ± 4.0%). However, for most of the subjects the errors ranged from low to moderate when using both the Multiple-Point and Two-$Point_{45-90}$ methods, while a higher proportion of subjects showed high errors using the Two-$Point_{45-75}$ method (**Table 3**). The validity analysis showed that all the 1RM prediction methods underestimated the actual 1RM (1.0 – 2.2 kg), they presented nearly perfect correlations, and the errors were not heteroscedastic (**Figure 2**). There were no fixed and proportional bias by means of the ordinary least-products regression analysis. Bland-Altman analysis showed different ranges of differences in agreement for the Multiple-point method (-2.2 ± 3.6 kg), Two-$Point_{45-75}$ (-1.4 ± 6.6 kg) and Two-$Point_{45-90}$ (-1.0 ± 3.6 kg).

[Table 2]

[Table 3]

[Figure 1]

[Figure 2]

DISCUSSION

The aim of this study was to (I) examine the accuracy to predict 1RM performance from barbell velocity during the free-weight overhead press and (II) explore the differences in the accuracy of the predicted 1RM between three velocity-based methods (i.e., Multiple-Point, Two-Point$_{45-75}$, Two-Point$_{45-90}$). The main finding was that the velocity-based methods might be viable tools to predict the free-weight overhead press 1RM based on nearly perfect correlations and no fixed or proportional bias. A novel finding of this study was that a method that only uses two points of the load-velocity relationship (i.e. Two-Point$_{45-90}$), could be even a better option compared with the Multiple-Point method to predict the free-weight overhead press 1RM in weightlifters based on lower absolute errors and a higher reliability. Nonetheless, these findings should be interpreted with caution since the predicted values based on the load-velocity methods do not accurately match with that of the overhead press 1RM; therefore, practitioners should be aware of the random errors that must be assumed when predicting the overhead press 1RM.

The advancement of affordable kinetic and kinematic technologies (e.g. LPT, accelerometers) have raised the load-velocity relationship modelling as an alternative to predict the 1RM [6,31,32]. Researchers have reported nearly perfect load-velocity relationships in different upper-body pressing exercises such as the bench press ($r = 0.97$ [33]) and seated press ($r \geq 0.92$ [2,11,14]). More specifically, researchers have found nearly perfect correlations between the actual and predicted bench press 1RM ($r = 0.98$ [18], $r = 0.99$ [22]), irrespective of the velocity-based method used. In line with these results, we found nearly perfect correlations between the actual and predicted overhead press 1RM for the three methods employed ($r = 0.98$ for Multiple-Point and Two-Point$_{45-90}$, and $r = 0.94$ for Two-Point$_{45-75}$). However, measures of association are not indicative of agreement between prediction methods; more important is the absolute agreement and random errors between prediction methods [35]. In this study, although there were no fixed and proportional bias by means of the ordinary least-products regression analysis, there were substantial absolute differences (Multiple-point = 3.5 ± 2.4 kg, 6.1 ± 3.7 %; Two-Point$_{45-75}$ = 4.9 ± 4.5 kg, 8.6 ± 6.2%; and Two-Point$_{45-90}$ = 3.1 ± 2.0 kg, 5.7 ± 4.0%) in the prediction of the 1RM. As an example, using the multiple point method, there might be an absolute error up to 9.8% in the estimation of the 1RM, which makes a large difference when selecting the loads for achieving the desired adaptations. In contrast, using the same rationale, the absolute error in the estimation of the 1RM could be as low as 2.4%. Similarly, the limits of agreement reported in the Bland-Altman analysis for the three velocity-based methods can be presumably high to accurately predicting the 1RM during the overhead press. However, the differences associated can be as low as -2.2, -1.4 and -1.0 kg for the Multiple-point, Two-Point$_{45-75}$ and

Two-Point$_{45-90}$, respectively (**Figure 2**). Therefore, practitioners should decide if they are willing to assume the associated errors with the proposed velocity-based methods.

Note that although it was not statistically significant, the Multiple and Two-Point$_{45-90}$ methods showed lower absolute errors in comparison to the Two-Point$_{45-75}$. This is further supported by the individual results reported in Table 3 that showed low to moderate errors in most of the subjects when using both the Multiple-Point (81.5%) and Two-Point$_{45-90}$ (85.2%) methods, while only 55.6% of the subjects showed low to moderate errors using the Two-Point$_{45-75}$ method. These results generally reinforce the importance of locating one load (i.e. point) close to the 1RM to have accurate predictions of the 1RM when using the load-velocity relationship, while testing multiple (i.e. more than one) loads below the closest load relative to the 1RM value does not seem necessary because it does not increase the precision in the estimation of the 1RM. However, if one load as close as 90%1RM is necessary to obtain a higher accuracy in the estimation of the free-weight overhead press 1RM, these velocity-based methods could be considered of less practical relevance than testing the direct 1RM for several reasons. First, based on our results and previous research the direct 1RM test is still the gold standard for evaluating maximal dynamic strength and is only 10% higher than the 90%1RM. Second, testing the direct 1RM does not require additional technology and analysis to capture the barbell velocity [16,36]. Third, although the idea of using only two loads (i.e. points) for modelling the load-velocity relationship might seem a time-efficient and less fatiguing option, in practice, lifters need a wider range of loads thorough the load-velocity relationship to adequately achieve a maximum (i.e. 100%1RM) or near maximum (i.e. 90%1RM) effort, as previously stated in different warm-up protocols [5,36].

There is an emerging body of research about the use of the load-velocity relationship for estimating maximal dynamic strength during resistance-training exercises [6,14,15,37]. Most of these investigations have been developed in the bench press exercise under fixed conditions, using a Smith machine, in order to increase the reliability and consistency of the values [6,14,37]. However, it has been recommended that to increase the applicability of velocity-based methods, practitioners should determine the load-velocity relationship during free-weight exercises because they are more frequently used in training and collect their own population-specific data, although a reduction in reliability could be expected [16]. To the authors knowledge, this is the first study which aimed to assess the load-velocity relationship during the free-weight overhead press in weightlifters. In this study, the inter-repetition reliability of mean velocity was acceptable (CV <15%) across the loads and suitable for modelling the load-velocity relationship with the three methods employed (**Table 2**), which may be indicative of a consistent technique of the participants, assuming the technological consistency of the kinematic device, previously reported [13]. The acceptable reliability of velocity data suggests that the errors of the 1RM prediction methods should not be caused by a low reliability of the mean velocity values used to construct the load-velocity relationships. Note that more variation and less consistency is found in the barbell velocity across the loads, compared with studies which have evaluated the reliability of the direct 1RM testing [5,36].

Nonetheless, this study has several limitations that need to be addressed in future research. First, the incremental loading test employed to predict the 1RM and the 1RM test were developed on different days. However, the free-weight overhead press 1RM test has been very reproducible with practically negligible differences [5] and, from an ecological point of view, practitioners may be more interested in getting the estimated 1RM in different days within a micro-cycle. Second, it is important to note that the mean velocity attained at the 1RM during the free-weight overhead press was not measured in this study; rather, this value was obtained based on previous research (0.24 $m \cdot s^{-1}$) [9]. In addition, researchers have demonstrated that the velocity of each one of the participant's 1RM may be recommended to accurately model the load-velocity relationship [16]. However, from an ecological point of view, practitioners may be more interested in getting the mean velocity value at which the 1RM is performed from the scientific literature and to put it into practice, as performed in this study. Nonetheless, based on previous findings that the velocity of the 1RM is exercise- and population-specific with strength-trained subjects performing the 1RM at lower velocities [38], future research is needed to determine the specific velocity at which the 1RM is developed in weightlifters and explore the differences in the accuracy of the prediction.

In conclusion, the Multiple-Point and Two-Point45-90 velocity-based methods might be viable tools to predict the free-weight overhead press 1RM in weightlifters based on nearly perfect correlations, no fixed and proportional bias and good reliability. However, practitioners must be aware of that the Multiple-point and Two-Point methods still have substantial errors associated with their accuracy to predict the 1RM (**Figure 1** and **Table 3**). Therefore, based on these findings, practitioners are encouraged to use the direct 1RM test, specifically when it is performed with free-weights, to adequately determine the overhead press 1RM, and prescribe loads in training. Nonetheless, practitioners can use the Multiple-Point and Two-Point$_{45\text{-}90}$

velocity-based methods to predict the free-weight overhead press 1RM in weightlifters if they are willing to assume the associated errors when applying to their training populations. This is of practical importance for strength and conditioning coaches since the free-weight overhead press is a foundational exercise in weightlifting programmes [5].

Table 1. Descriptive characteristics of the subjects

Sample size	Age (yrs)	Height (cm)	BM (kg)	WL training experience (years)	Overhead press 1RM (kg)
Males = 16	31.4 ± 6.7	178.9 ± 6.2	82.8 ± 12.5	4.4 ± 5.6	70.5 ± 11.7
(95% CI)	(27.8 – 34.9)	(175.7 – 182.2)	(76.1 – 89.4)	(0.6 – 8.1)	(62.6 – 78.4)
[range]	[23 to 42]	[169 to 190]	[59 to 102]	[0.5 to 22]	[53.5 to 95]
Females = 11	29.0 ± 6.3	165.3 ± 4.6	60.7 ± 4.8	2.9 ± 2.5	37.5 ± 4.9
(95% CI)	(24.7 – 33.3)	(162.2 – 168.4)	(57.5 – 63.9)	(1.2 – 4.6)	(34.2 – 40.7)
[range]	[20 to 43]	[161 to 175]	[56 to 71]	[1 to 8]	[31 to 47]
All = 27	30.4 ± 6.5	173.4 ± 8.8	73.8 ± 14.9	3.8 ± 4.6	57.0 ± 19.0
(95% CI)	(27.8 – 33.0)	(169.9 – 176.8)	(67.9 – 79.7)	(0.7 – 6.8)	(44.2 – 69.8)
[range]	[20 to 43]	[161 to 190]	[55.5 to 102]	[0.5 to 22]	[31 to 95]

BM = body mass, WL weightlifting, 1RM = one repetition maximum, CI confidence interval. Data are presented as mean and SD.

Table 2. Characteristics of the loads used for the modelling of the individualized load-velocity relationships during the overhead press exercise.

	Load 1	Load 2	Load 3	Load 4	Load 5
Relative load (%1RM)	30	45	60	75	90
Absolute load (kg)	17.0 ± 5.6	25.6 ± 8.6	34.2 ± 11.5	42.5 ± 13.9	51.1 ± 17.1
(95%CI)	(14.8 – 19.2)	(22.2 – 29.0)	(29.7 – 38.8)	(37.0 – 48.0)	(44.4 – 57.9)
[Range]	[10 to 28]	[14 to 43]	[18 to 57]	[23 to 66]	[28 to 85]
Mean velocity ($m \cdot s^{-1}$)	1.3 ± 0.2	1.1 ± 0.1	0.8 ± 0.1	0.6 ± 0.1	0.4 ± 0.1
(95%CI)	(1.3 – 1.4)	(1.0 – 1.1)	(0.8 – 0.9)	(0.5 – 0.6)	(0.3 – 0.4)
[Range]	[1.1 to 1.8]	[0.8 to 1.3]	[0.6 to 1.1]	[0.4 to 0.8]	[0.2 to 0.6]
ICC	0.88	0.86	0.81	0.93	0.9
(95%CI)	(0.76 – 0.94)	(0.75 – 0.93)	(0.62 – 0.91)	(0.85 – 0.97)	(0.78 – 0.95)
[Interpretation]	[Good]	[Good]	[Moderate]	[Good]	[Good]
CV (%)	4.5	4.8	5.9	4.1	9.0
(95%CI)	(3.6 – 6.2)	(3.8 – 6.5)	(4.6 – 8.1)	(3.2 – 5.6)	(7.1 – 12.3)
[Interpretation]	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

1RM, 1-repetition maximum, CI, confidence interval, ICC, intraclass correlation coefficient. CV, coefficient of variation. Data are presented as mean and SD.

Table 3. Count of subjects that showed low (<5.0%), moderate (5.0%–10%), and high (>10.0%) errors for the different 1RM prediction methods.

Categorization of errors	Multiple-Point	Two-Point$_{45-75}$	Two-Point$_{45-90}$
Low	12	7	14
Moderate	10	8	9
High	5	12	4

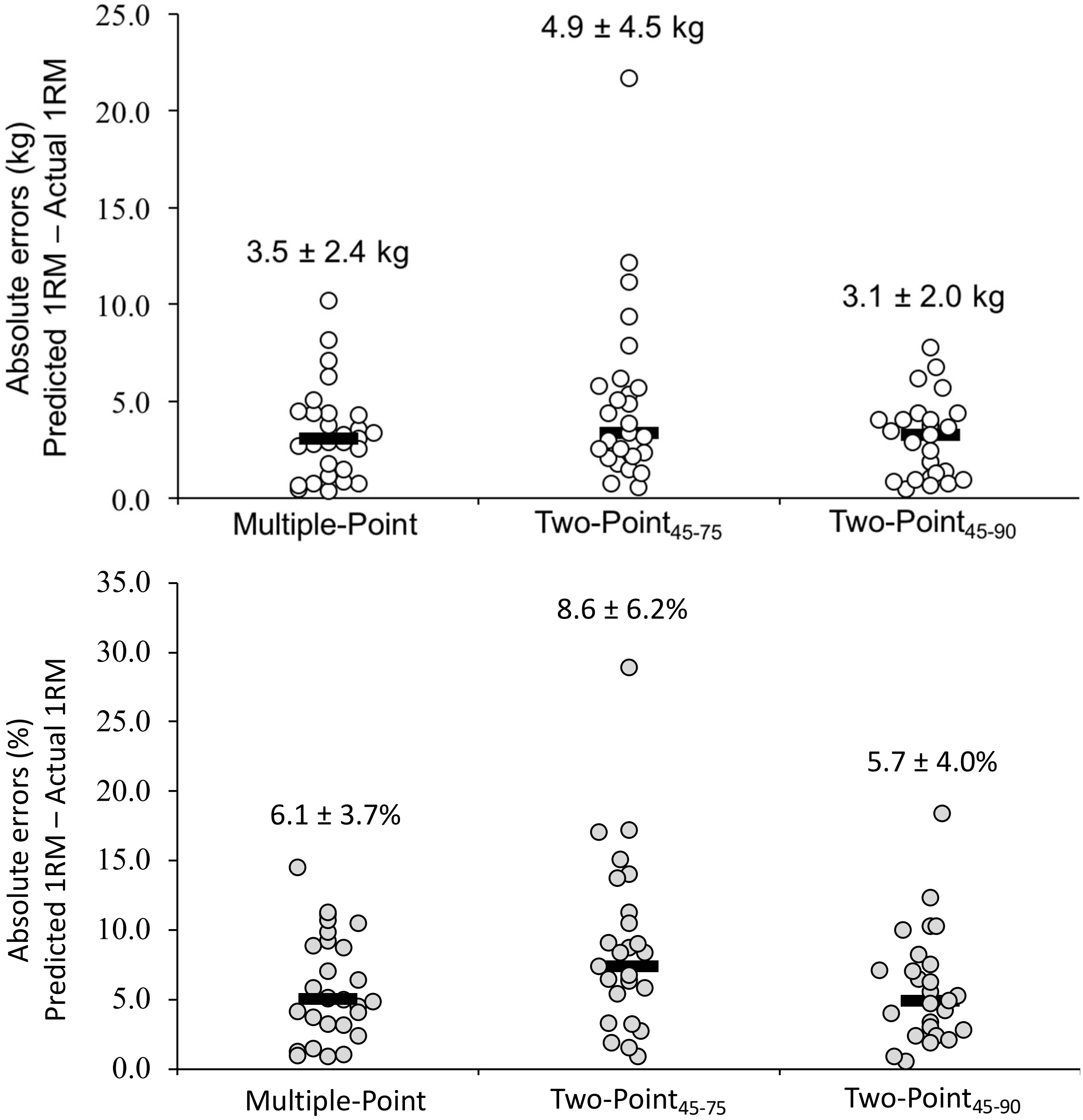

Figure 1. Absolute errors expressed in raw values (kg) and relative to the 1RM (%) observed for the different 1-repetition maximum (1RM) prediction methods with respect to the directly measured 1RM during the overhead press exercise. Numbers denote the means and standard deviations, the black rectangle the median value, and the circles the individual data points.

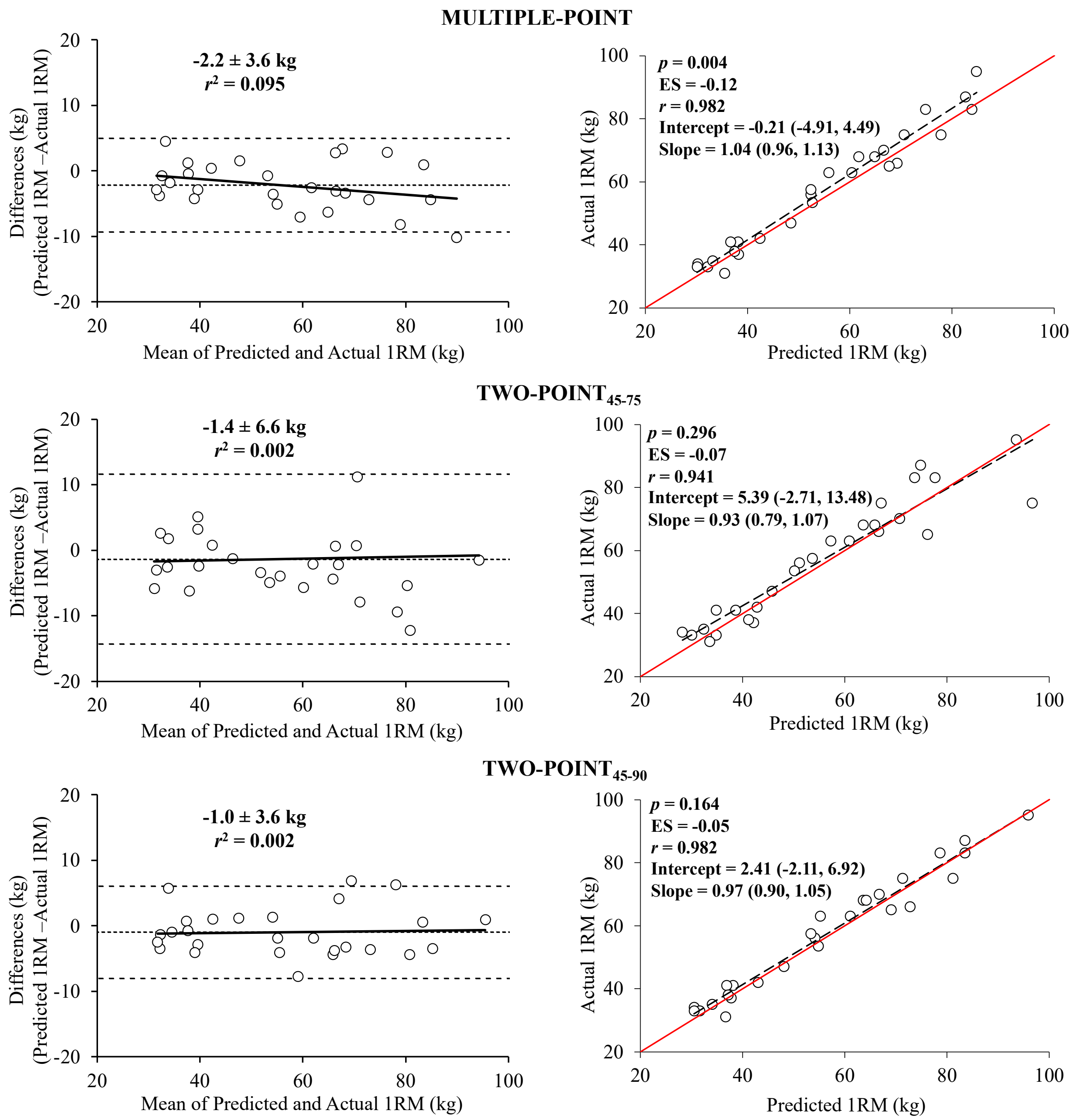

Figure 2. Agreement between the directly measured 1-repetition maximum (1RM) and the 1RM estimated by the Multiple-Point method (30-45-60-75-90% of 1RM; upper panels), Two-Point$_{45-75}$ method (45-75% of 1RM; middle panels), and Two-Point$_{45-90}$ method (45-90% of 1RM; lower panels) during the overhead press exercise. Left hand graphs present the Bland-Altman plots depicting the systematic bias ± random differences, and heteroscedasticity of errors (r^2). Right hand graphs show the ordinary least-products regressions to explore the concurrent validity of the predicted 1RMs through the Pearson's product-moment correlation coefficients (r), while the intercept and slope with their 95% confidence intervals were used to assess fixed and proportional bias. In addition, the relationship between the actual 1RM and predicted 1RM depicting the identity line (straight red line), effect sizes (ES; [Predicted 1RM – Actual 1RM] / SD both), and p-values obtained from a paired samples t-test.

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