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Evaluation of Load Velocity Profiles with Varying Warm-up Sets and Relative Intensities

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ABSTRACT

International Journal of Exercise Science 14(4): 971-979, 2021. The purpose of this study was to determine whether the number of warm-up sets and relative intensity impacts the prediction of velocity-based one-repetition maximum (1RM) values. Twenty resistance-trained individuals (males: n = 10, females: n = 10) participated in this study. Warm-up sets consisted of subject's bench-pressing loads at 50 (five-repetitions), 70 (three-repetitions), and 90% (one-repetition) of estimated 1RM. A maximum of four attempts were performed to determine 1RM, while recording mean concentric velocity (MCV) using a linear position transducer during warm-up and 1RM trials in order to develop load-velocity profiles. Specifically, four different velocity-based 1RM equations (EQ) were developed from the warm-up sets of 50, 70, and 90% (MCV-EQ1), 50 and 90% (MCV-EQ2), 70 and 90% (MCV-EQ3), and 50 and 70% (MCV-EQ4). Constant error (CE) for the MCV prediction equations were not statistically significant for any comparisons (CEs = 0.80 to 2.96kg, all $p > 0.05$). Correlation coefficients between the MCV prediction methods and measured 1RM were near perfect for all comparisons ($r \geq 0.98$, all $p < 0.001$). The standard error of estimate (SEE) and 95% limits of agreement (LOAs) were lowest for MCV-EQ1 (7.86 kg and ± 15.00 kg, respectively) and slightly higher for MCV-EQ3 (9.24 kg and 17.74 kg, respectively). Nonetheless, SEEs and 95% LOAs for MCV-EQ2 (8.10 kg and ± 15.55kg, respectively) and MCV-EQ4 (8.38 kg and ± 16.08 kg, respectively) were similar as MCV-EQ1. Current study results indicated that an additional warm-up set only slightly increases the accuracy of velocity-based 1RM estimations. Furthermore, larger differences in relative intensity will help produce slightly more accurate 1RM values.

KEY WORDS: Bar velocity, linear position transducer, resistance training, weightlifting

INTRODUCTION

Muscular strength is one of the five health-related components of physical fitness (17, 24). Further, muscular strength is often assessed via one-repetition maximum (1RM) (12, 14). Multiple exercises have been used to assess 1RM, which is quantified as the greatest load lifted with full range-of-motion without failure (22). Moreover, it has been suggested that 1RM testing is the recommended method when seeking to evaluate muscular strength measures such as bench press, back squat, leg press, etc. (4). However, traditional 1RM protocols, which require lifting until failure, may not be feasible for all populations. For example, 1RM protocols may not be recommended for novice lifters who are becoming familiar with proper exercise technique. As a result, alternative methods have been proposed for assessing 1RM (2).

Bar velocity is often evaluated in strength and conditioning research and has been used to estimate 1RM (6, 7, 13). Particularly, mean concentric velocity (MCV) is a technique that is used to estimate 1RM on various weight lifting exercises. The MCV of a lift is defined as the average speed attained during the concentric phase of a movement (9, 11). Furthermore, studies have shown a near-perfect inverse relationship between velocity and loads where velocity tends to decrease as loads increase in intensity (20, 21). Technology that can easily be utilized in strength and conditioning facilities, such as linear position transducers, provide health and fitness professionals a field-based tool for assessing MCV (5, 16). Consequently, this allows a practical technique to be employed for estimating 1RM instead of a traditional 1RM protocol.

Although highly desired, the necessity to incorporate numerous submaximal warm-ups sets may restrict application of linear position transducers for the estimation of 1RM in strength and conditioning settings due to time necessity. For example, four to six warm-up sets was originally proposed for estimating velocity-based 1RM (11). However, researchers have used as many as nine warm-up sets to predict velocity-based 1RM (18). As previously mentioned, an excessive amount of warm-up sets could prevent velocity-based 1RM from being widely utilized in strength and conditioning settings, which often have limited time availability. In addition, an extensive amount of warm-up sets will likely result in a similar time commitment as traditional 1RM protocols.

The use of fewer warm-up sets to estimate 1RM has become an area of interest in previous research. For example, recent research has sought to determine the accuracy of velocity-based 1RM when employing two to five warm-up sets (1). Employing fewer warm-up sets than previously recommended would be useful for strength and conditioning professionals working with athletes who have limited time availability for 1RM testing. However, issues with previous research evaluating the estimation of 1RM values with fewer warm-up sets are 1) exclusion of female participants, 2) evaluation of exercises not traditionally used for 1RM protocols (i.e., lat-pulldown and seated row), and 3) exclusion of free weight bench press, which is commonly used for assessing muscular strength (13, 18, 19, 21). Therefore, the purpose of this study was to determine whether the number of warm-up sets and relative intensity impacts the prediction of velocity-based 1RM values.

METHODS

Participants

Participant characteristics and performance metrics are displayed in Table 1. Twenty resistance trained individuals consisting of females (n = 10) and males (n = 10) participated in the current study. Resistance trained individuals needed to meet the following criteria in order to participate in the study: 1) 18 - 45 years of age , 2) no prior musculoskeletal injuries six months prior to testing, 3) experience with bench press for at least six months, and 4) able lift 50% of body weight. Participants were advised to avoid any upper body training at least 48 hours prior to the testing session. The current study was approved by the Institutional Review Board of the host university and followed ethical standards previously outlined (15).

Table 1. Subject characteristics and performance metrics.

	Females (n = 10)			Males (n = 10)		
	(Mean ± SD)	Minimum	Maximum	(Mean ± SD)	Minimum	Maximum
Age (yrs.)	26±6	18	38	28 ± 8	18	42
Height (cm)	162.61±5.03	156.60	174.00	177.22 ± 9.92	162.50	188.90
Weight (kg)	63.35 ± 4.58	57.10	71.80	97.32 ± 20.09	75.90	143.10
50% Velocity ($m \cdot sec^{-1}$)	0.65 ± 0.15	0.52	0.98	0.87 ± 0.15	0.69	1.12
70% Velocity ($m \cdot sec^{-1}$)	0.50 ± 0.13	0.35	0.78	0.65 ± 0.12	0.52	0.87
90% Velocity ($m \cdot sec^{-1}$)	0.33 ± 0.11	0.12	0.53	0.41 ± 0.08	0.34	0.60
1RM Velocity ($m \cdot sec^{-1}$)	0.18 ± 0.04	0.12	0.25	0.24 ± 0.09	0.11	0.40
Measured 1RM (kg)	50.91 ± 7.89	40.91	65.91	129.55 ± 30.47	90.90	184.09

Protocol

Testing consisted of one visit to the Exercise Physiology Laboratory in the morning hours (8:00 - 10:00 AM). Prior to the testing sessions, participants were required to refrain from the intake of caffeine and to avoid alcohol consumption for twelve hours. In addition, participants provided informed consent and completed a medical history questionnaire before participation. Next, participants completed a standard warm-up consisting of a light jog (approximately 5km/h) for five minutes, followed by upper body dynamic stretching of the chest, shoulders and triceps. Participants performed warm-up sets of five, three, and one repetition at loads of 50, 70 and 90% of their estimated 1RM. After the completion of each warm-up set, subjects had a recovery period of two minutes for warm-up sets at 50% 1RM, whereas four minutes of recovery were allowed for 70 and 90% 1RM loads. Next, participants performed a maximal bench press, with an allotted recovery period of four minutes in between each attempt and gradual weight increase of 2.5 kg until the participant reached their failed attempt.

A maximum of four attempts were performed in order to determine the 1RM (8). The MCV of the subject's 1RM was determined with the use of a linear position transducer (GymAware© PowerTool, Kinematic Performance Technology, Canberra, Australia) that was attached in a vertical position towards the end of the right side of the barbell. Each subject was instructed to perform the bench press as fast as possible during the concentric phase of the movement. Also, as subjects reached the eccentric phase, they were instructed to perform this stage in a touch and go movement. During each warm-up set (i.e., MCV_{50}, MCV_{70}, and MCV_{90}), the highest MCV value was recorded and used in order to develop load velocity profiles. Consequently, four velocity-based 1RM equations were developed using the warm-up sets as follows: MCV-EQ1 (50, 70, and 90%), MCV-EQ2 (50 and 90%), MCV-EQ3 (70 and 90%) and MCV-EQ4 (50 and 70%).

Statistical Analysis

Statistical analyses were performed using SPSS 26.0 software (SPSS Inc., Chicago, IL, USA). All data are presented as mean ± standard deviations. The accuracy of the MCV prediction equations versus the measured 1RM were determined by computing the constant error, (e.g.,

[CE] = MCV-EQ1 – 1RM), Pearson's correlation coefficient (r), and the standard error of estimate (SEE). Effect sizes (ES) of the differences were determined using Cohen's d. The method of Bland-Altman (3) was also used to identify the 95% limits of agreement (LOAs) of predicted 1RM (kg) for the MCV equations. An a priori alpha level was set at 0.05.

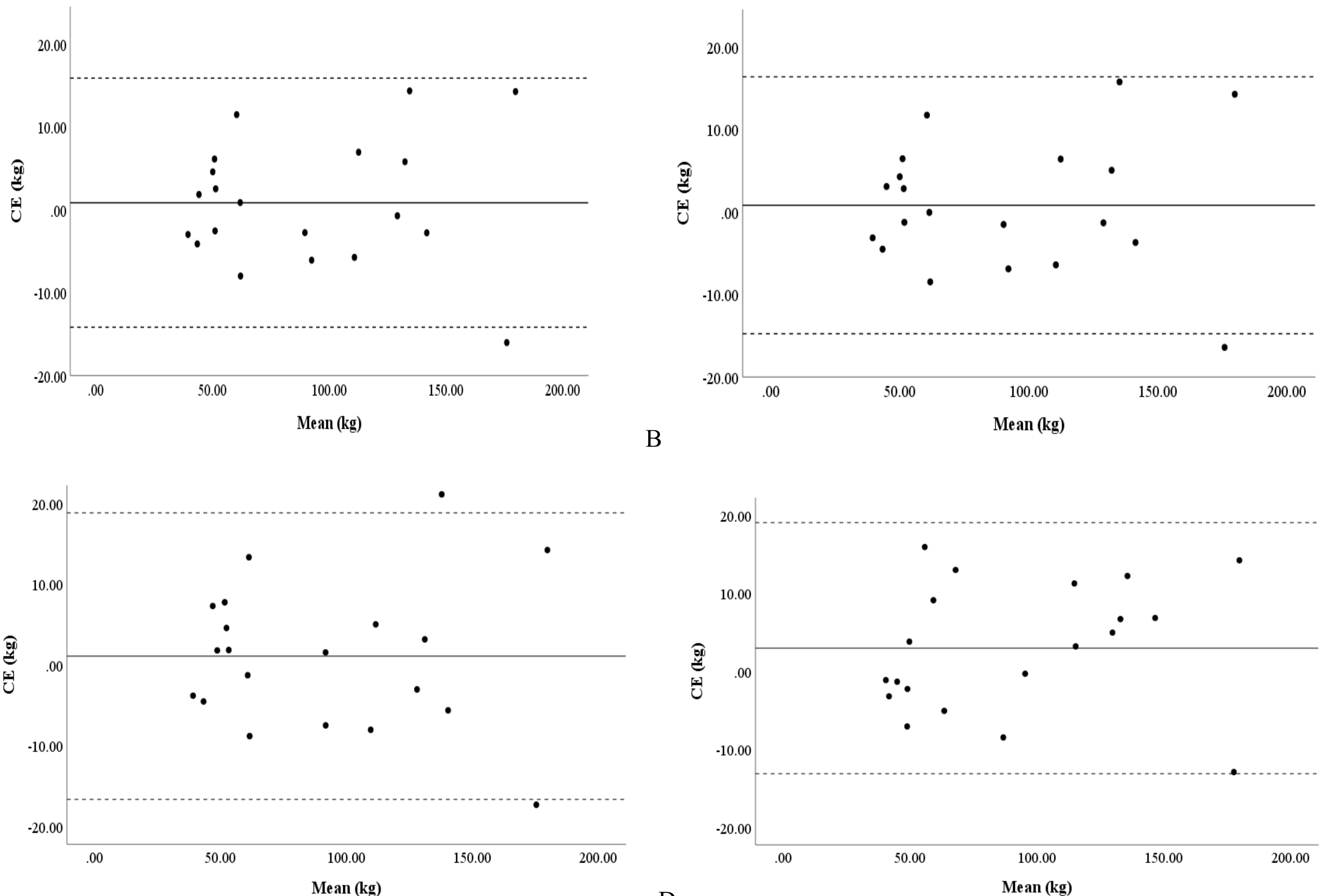
RESULTS

Statistical outcomes are displayed in Table 2. Evaluation of mean differences revealed the CE for the MCV prediction equations were not statistically significant for any comparisons against measured 1RM (CEs = 0.80 to 2.96 kg, ES = 0.02 to 0.06, all $p > 0.05$). In addition, the correlation coefficients between the MCV prediction methods and measured 1RM were near perfect for all comparisons ($r \geq 0.98$, all $p < 0.001$). The standard error of estimate (SEE) and 95% LOAs was lowest for MCV-EQ1 (7.86 kg and ± 15.00 kg, respectively) and highest for MCV-EQ3 (9.24 kg and 17.74 kg, respectively). Nonetheless, the SEEs and 95% LOAs for MCV-EQ2 (8.10 kg and ± 15.55 kg, respectively) and MCV-EQ4 (8.38 kg and ± 16.08 kg, respectively) were similar as MCV-EQ1. Bland-Altman plots of the 95% LOAs are depicted in Figure 1.

Table 2. Values ± SD for MCV prediction equations and measured 1RM in male and female weightlifters (n = 20).

	(Mean ± SD)	p-value	Cohen's d	r	SEE	CE ± 1.96 SD	Upper	Lower
MCV-EQ1	91.03 ± 46.16	0.64	0.02	0.99	7.86	0.80 ± 15.00	15.81	-14.20
MCV-EQ2	90.99 ± 46.00	0.67	0.02	0.99	8.10	0.76 ± 15.55	16.31	-14.79
MCV-EQ3	91.29 ± 45.61	0.61	0.02	0.98	9.24	1.06 ± 17.74	18.81	-16.68
MCV-EQ4	93.19 ± 47.35	0.12	0.06	0.99	8.38	2.96 ± 16.08	19.04	-13.12
Measured 1RM	90.23 ± 45.79	---	---	---	---	---	---	---

1RM = measured one repetition maximum (kg), MCV = mean concentric velocity, EQ1 = velocities obtained at 50, 70, and 90%1RM, EQ2 = velocities obtained at 50 and 90% 1RM, EQ3 = velocities obtained at 70 and 90% 1RM, EQ4 = velocities obtained at 50 and 70% 1RM, SEE = standard error of estimate, CE = constant error, SD = standard deviation.



A B C D

Figure 1. Bland-Altman plots for load velocity profiles used to estimate 1RM on bench press. The middle solid line represents the constant error between the prediction models (MCV-EQ1, MCV-EQ2, MCV-EQ3, and MCV-EQ4) and measured 1RM. The two outside dashed lines indicate the 95% confidence interval of the bias (difference) and their means. Separate Bland-Altman plots depicting estimated 1RM in the load velocity profiles are displayed for (A) MCV-EQ1, (B) MCV-EQ2, (C) MCV-EQ3, (D) MCV-EQ4 .

DISCUSSION

The main findings of this study showed that MCV-EQ1 produced the lowest SEE and 95% LOAs. These findings support the notion that more warm-up sets may lead to an improved prediction of 1RM via bar velocity. Nonetheless, the individual error was also fairly similar when evaluating MCV-EQ2, MCV-EQ3, and MCV-EQ4, whereas the group error (CE) was lowest in the former, which employed warm-up sets of 50 and 90% 1RM. This is an interesting finding that reveals two separate warm-up sets may produce similar values as three separate warm-up sets. Furthermore, incorporating warm-up sets that have a wider variance (e.g., 50 and 90% 1RM [MCV-EQ2], instead of 50 and 70% 1RM [MCV-EQ4]) may increase the precision of a velocity based 1RM prediction equation. Accordingly, results of the current study are promising and indicate that an additional warm-up set (i.e., three warm-up sets instead of two warm-up sets) may slightly increase the accuracy of velocity-based 1RM estimations.

Previous research has yielded conflicting findings when estimating 1RM via velocity. For example, Banyard et al. (1) revealed that five (20, 40, 60, 80, and 90% 1RM) warm-up sets produced better SEE values than three (20, 40, and 60% 1RM) and four (20, 40, 60, and 80% 1RM) warm-up sets. These findings are similar to the current study, which revealed three warm-up sets (i.e., MCV-EQ1) produced slightly better SEE and 95% LOAs than two warm-up sets (i.e., MCV-EQ2, MCV-EQ3, MCV-EQ4). Similarly, four (40, 55, 70, 85% 1RM) warm-up sets have been found to produce better SEEs than two (i.e., 40 and 85% 1RM) warm-up sets on the seated cable row exercise (18). In contrast, two warm-up sets (i.e., 40 and 85% 1RM) were found to produce lower SEE values than four warm-up sets (i.e., 40, 55, 70, 85% 1RM) on the lat pull-down, which conflicts with the present study results. Current study results also partially conflict with previous research that revealed velocity-based 1RM employing three, four, and five warm-up sets overestimated actual 1RM by 5 to 10 kg (i.e., CE) on the deadlift. However, authors noted that submaximal ranges performed at higher loads tend to show better accuracy, which is in partial agreement with the current study findings that showed MCV prediction equations employing 90% 1RM produced better SEEs and 95% LOAs (19).

Reasons for current study findings are worth further consideration. For instance, previous research revealed velocity-based 1RM on the deadlift and back squat were not valid (1, 19). One noticeable difference was that the aforementioned studies required participants to be able to lift at least 1.5 times their body mass whereas the current study only required participants to lift 0.5 times their body mass (1, 19). Furthermore, the participants of Banyard et al. (1) and Ruf et al. (19) consisted of male participants who had a relative strength of 2.0 and 1.7 $kg \cdot kg^{-1}$, respectively, which is higher than values observed of male participants in the current study (i.e., 1.1 $kg \cdot kg^{-1}$). Accordingly, it seems plausible that the variations in strength level across studies might have implications on testing outcomes. This postulation is partially supported by previous research, which found that weaker males present a steeper load-velocity profile than their stronger male counterparts when evaluated on the bench press (23). It is worth noting that it is outside the scope of the current study to stratify based upon strength level due to the limited number of participants within each sex (i.e., ten male and ten female). As a result, systematic evaluations on the impact of strength level across different 1RM protocols (e.g., deadlift, squat, etc.) when seeking to estimate velocity-based 1RM are warranted in the future.

Previous research has suggested that fewer warm-up sets lead to greater individual variability when employing velocity-based 1RM (1). Therefore, reasons for this rationale are worth discussing. For example, the current study concluded that three warm-up sets (i.e., MCV-EQ1) marginally improved the accuracy of load velocity profiles when compared to two warm-up sets (i.e., MCV-EQ2, MCV-EQ2, and MCV-EQ3). Nonetheless, the individual error of MCV-EQ2, which employed 50% and 90% 1RM velocities, performed slightly better than MCV-EQ3 (i.e., 70% and 90% 1RM) and MCV-EQ4 (i.e., 50% and 70% 1RM). Interestingly, Jidovtseff et al. (10) suggested that differences between the lightest and heaviest loads used for prediction should exceed 0.5 $m \cdot sec^{-1}$ when developing load velocity profiles. This recommendation along with current study findings, seems to indicate that larger variations in MCV will likely help produce a slightly more accurate load velocity profile. For example, the average MCVs for 50, 70, and 90% 1RM in the present study were 0.76, 0.57, and 0.37 $m \cdot sec^{-1}$, respectively. These findings indicate the differences in mean velocity for MCV-EQ2 (difference = 0.39 $m \cdot sec^{-1}$) were larger than MCV-EQ3 (difference = 0.20 $m \cdot sec^{-1}$) and MCV-EQ4 (difference = 0.19 $m \cdot sec^{-1}$), which may potentially serve as an explanation for slightly better outcomes observed in the former. This notion is further supported by previous research that has shown two warm-up sets of 40 and 85% 1RM can be used to accurately develop load velocity profiles (18).

Although the current study adds to previous literature, it is not without limitations. First, researchers should employ caution prior to generalizing results to exercises other than the free weight bench press. It is possible that different results would have been obtained with a different exercise. Another limitation of the current study is that results should not be generalized to velocity-based devices other than what was used in the current study. For example, it is not certain whether results would have come out similar had other velocity-based methods, such as TENDO unit or PUSH been used. Consequently, future studies may consider evaluating additional devices to determine if they are consistent with current study findings. Finally, the menstrual cycle phase of female subjects was not controlled. Therefore, hormonal differences due to the menstrual cycle are possible and may have had implication for female testing results of the present study. However, since procedures did not consist of a training intervention, it is likely this had minimal effect on study outcomes.

In conclusion, current study results indicated that an additional warm-up set (i.e., three warm-up sets instead of two warm-up sets) only slightly increases the accuracy of velocity-based 1RM estimations. Another finding in the current study revealed that larger differences in relative intensity (e.g., 50 and 90% instead of 50 and 70%) will help produce slightly more accurate 1RM values. This is of significance in strength and conditioning facilities that have limited time availability, which often leads to an inability to complete 1RM testing protocols on large team settings. Nonetheless, in the event that time is not restricted, the use of three warm-up sets is advised. Moreover, it is worth noting that a large increase from 50 to 90% 1RM is a rather large increase in relative intensity. Accordingly, strength and conditioning professionals are encouraged to employ appropriate safety precautions. Altogether, initial recommendations and prior research have used excessive warm-up sets to develop load velocity profiles, which limits the use of velocity-based 1RM. However, current study findings seem to suggest that two warm-up sets produces similar 1RM values as three warm-up sets. It is possible that excessive warm-up sets may not be necessary when developing load velocity profiles.

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