DOES THE LOAD-VELOCITY RELATIONSHIP PREDICT MAXIMUM DYNAMIC STRENGTH IN POWER CLEAN FROM THE KNEE?

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Abstract:

This study investigated the predictive validity and reliability of the load-velocity relationship with the one-repetition maximum test (1RM) in power clean from the knee exercise (PC). Initially, 12 healthy young males, with no PC experience, underwent eight sessions to learn the PC technique. After the learning period, the participants visited the laboratory on four more occasions with intervals between the visits from 72 to 96 h. The first two sessions were dedicated to the actual 1RM tests, while the last two sessions were performed to measure the barbell's load-velocity relationship at 30%, 45%, 60%, 75%, and 90% of PC 1RM. The highest peak velocity recorded at each load was used to establish the linear regression equation and, consequently, to predict 1RM values. As a result, a low validity was observed between the highest actual 1RM value and the predicted 1RM in sessions 1 and 2 (typical errors = 3.6 to 5.0 kg, coefficients of variation = 6.03 to 8.21%, effect sizes = -1.23 to -1.00, and Bland-Altman bias = 8.5 to 11.7 kg). For reliability, higher measurement errors (intraclass correlation coefficient, typical error, coefficient of variation, and width of limits of agreement at 95%) were observed for the predicted 1RM compared to the actual 1RM test. In conclusion, the load-velocity relationship was not able to predict the 1RM value with high accuracy in the PC from the knee. Moreover, the predicted 1RM presented inferior reliability than the actual 1RM test.

Key words: *maximum strength, weightlifting, velocity, velocity-based training, performance*

Introduction

The one-repetition maximum (1RM) can be defined as the maximum weight that an individual can lift in one repetition. Usually, the 1RM test is used to determine load prescription and to verify resistance training program progression (Kraemer & Ratamess, 2004). Despite the practical and useful results, the application of the 1RM test may be considered sometimes disadvantageous due to, for example: (I) a high time demand for its execution (Chapman, Whitehead, & Binkert, 1998; Garcia-Ramos, et al., 2018a; Gonzalez-Badillo, Marques, & Sanchez-Medina, 2011; Loturco, et al., 2016, 2017), (II) fast 1RM changes in the first weeks of training in individuals with low experience in resistance training (Abe, DeHoyos, Pollock, & Garzarella, 2000), and (III) risk of injury when performed incorrectly (Niewiadomski, et al., 2008).

To minimize these disadvantages, the use of the load-velocity relationship (i.e., measuring the bar speed at different submaximal loads) is a practical alternative to predict 1RM percentages (Banyard, Nosaka, & Haff, 2017; Garcia-Ramos, et al., 2018a; Loturco, et al., 2016, 2017; Perez-Castilla, Garcia-Ramos, Padial, Morales-Artacho, & Feriche, 2018; Ruf, Chery, & Taylor, 2018). Briefly, through a linear regression equation, the value of 1RM can be predicted from the load-velocity relationship of just one repetition (Banyard, et al., 2017; Garcia-Ramos, et al., 2018a; Loturco, et al., 2016, 2017; Perez-Castilla, et al., 2018; Ruf, et al., 2018). Using bar-velocity facilitates load adjustments during a resistance training program, requiring less time, besides having validity and reliability with the 1RM test (Garcia-Ramos, et al., 2018a; Loturco, et al., 2016, 2017; Perez-Castilla, et al., 2018). For example, high validity (accuracy ≥ 94%) and reliability (coefficient of variation ≤ 5.7%) of the load-velocity relationship and the 1RM test were reported for the half squat and bench press exercises (Banyard, et al., 2017; Loturco, et al., 2016, 2017; Perez-Castilla, et al., 2018).

According to the information presented previously, the load-velocity relationship may be an interesting alternative to predict the 1RM value. However, it is important to note that linear regression equations and, consequently, the validity and reliability, are exercise-dependent (Perez-Castilla, et al., 2018). Therefore, the results reported for the half-squat and bench press cannot be extrapolated to other exercises.

The load-velocity relationship has been poorly investigated in weightlifting derivatives. Weightlifting derivatives are exercises that omit a portion of the snatch or clean and jerk (Suchomel, Comfort, & Stone, 2015). Among the numerous weightlifting derivatives, the power clean from the knee (PC) has been extensively used in different sports training programs (Weldon, et al., 2022). It should be mentioned that the PC is considered an important exercise due to a higher power production and similarities with some motor tasks (e.g., vertical jumps and sprints) than traditional strength exercises, such as squat (McBride, Haines, & Kirby, 2011). In addition, PC may improve vertical jumps and sprint even in individuals without experience in the snatch, clean and jerk, and other weightlifting derivatives (Arabatzi & Kellis, 2012; Keller, Koob, Corak, Von Schoning, & Born, 2018; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005). Finally, the PC 1RM value is frequently used as a parameter for load prescription of some weightlifting derivatives such as mid-thigh clean pull and countermovement shrug. Considering the PC's widespread application and relevance as a weightlifting derivative and the intrinsic difficulties involved in 1RM test execution, it becomes necessary to verify if the load-velocity relationship in PC allows the prediction of 1RM value with high validity and reliability.

Therefore, the purpose of this study was to investigate the predictive validity and reliability of the load-velocity relationship to predict the 1RM value for the PC exercise. We hypothesized that the load-velocity relationship would present a high validity and reliability.

Methods

Participants

Twelve healthy young male participants were recruited for this study (age 21.5 ± 2.8 years, height 1.7 ± 0.6 m, and body mass [BM] 70.9 ± 7.6 kg). Participants were included if they met all the following criteria: at least one year of experience in resistance training (had an average of 2.8 ± 1.1 years); at least one year of squat experience (had an average 1.4 ± 0.3 years); 1RM to body mass ratio in the half-squat exercise above 1.5 $kg \cdot kg^{-1}$ (had an average 2.1 ± 0.2 $kg \cdot kg^{-1}$), and no experience in the snatch, clean and jerk, or any weightlifting derivative. The exclusion criterion was a history of lower and/or upper-body injury for six months preceding their participation in the study. The study was initiated with 12 participants and there was no dropout during the study. It is important to note that the participants had no experience in snatch, clean and jerk, and weightlifting derivatives, while a recent study with goals similar to the present study used a sample with at least one year of experience in weightlifting derivatives (Berton, et al., 2021).

Finally, they were informed about the purpose of the study, experimental procedures, and all potential risks involved before signing a consent form. The study protocol was approved by the Ethics and Research Committee of the local University and it complied with all ethical standards for research involving human participants set by the Declaration of Helsinki.

Procedure

We investigated the predictive validity and reliability of the load-velocity relationship for the prediction of the 1RM value in the PC exercise. To collect data, participants visited the laboratory on 13 occasions. In the first visit, body height, body mass, and half-squat 1RM were assessed only to characterize the sample. From the second to ninth visits (8 sessions), the participants underwent a PC learning period. This strategy was adopted due to the PC complexity and to improve participants' safety during the 1RM test of the same exercise. We selected this sample because the PC is one of the weightlifting derivatives commonly used in training programs for individuals with no or low weightlifting experience (Arabatzi & Kellis, 2012; Keller, et al., 2018; Tricoli, et al., 2005).

After the learning period, the participants visited the laboratory on four additional occasions with intervals between the visits of 72 to 96 h. The first two sessions were dedicated to the actual PC 1RM tests, while the tests to predict the 1RM based on the load-velocity relationship were conducted in the last two sessions. Five loads (30%, 45%, 60%, 75%, and 90% of PC 1RM) were employed through the load-velocity continuum to establish a linear regression equation and, consequently, to predict the 1RM value. It is worth noting that the order of the tests (1RM and load-velocity relationship) was not randomized, and researchers and participants were not blinded during the study period.

Learning protocol

All participants underwent eight training sessions over four weeks (two sessions per week, with an interval between them of 48-72 h). The learning protocol was composed of the following exercises: (1) hip and knee extension; (2) hip and knee extension, 1-second pause, and ankle extension; (3) hip and knee extension, 1-second pause, ankle extension, 1-second pause, and clean grip upright; (4) clean grip upright followed immediately by the catch phase; (5) mid-thigh clean pull; (6) high pull; and (7) PC. The clean grip upright followed immediately by the catch phase and mid-thigh clean pull were initiated with the barbell at the mid-thigh level. All other exercises were initiated with the barbell just above the patella's top edge (adjusted by wooden blocks). Also, all participants during all sessions used the regular grip (hook grip was not allowed). For more details about the PC execution and wooden blocks adjustments see Berton et al. (2021).

Participants performed three sets of six repetitions for all exercises. A 1-min rest was allowed between sets and exercises. In weeks one and two, the participants performed all exercises with a standard Olympic barbell (20 kg) (Fortify, São Paulo, Brazil) plus one 1.5 kg custom-made weight plate (diameter of 45 cm) to each side of the barbell. In the last two weeks, a 5 kg plate (diameter 45 cm) was added to each side of the standard Olympic barbell (total weight = 30 kg). The use of this weight was previously demonstrated as adequate for the PC learning (Sakadjian, Panchuk, & Pearce, 2014). Finally, to maximize learning, verbal feedback were provided during the execution of each exercise and in the rest intervals (Rucci & Tomporowski, 2010; Sakadjian, et al., 2014).

PC 1RM test

Initially, participants performed a general warm-up on a cycle ergometer at 20 km·h^{-1} for 5-min. After a 1-min rest, they performed a specific warm-up consisting of three PC repetitions at 30%, 50%, and 70% of the estimated 1RM, and one repetition at 90% 1RM (Suchomel, Wright, Kernozek, & Kline, 2014a). A 2-min rest was provided between the loads. It is important to mention that the used loads were estimated by the researchers based on the experience of each participant during the learning period. Three minutes after the specific warm-up, participants had up to five attempts to attain the PC 1RM value (Brown & Weir, 2001). A 3-min rest was allowed between the attempts.

The 1RM value was defined as the highest load lifted, through previously defined technical parameters (Suchomel, Beckham, & Wright, 2014b; Suchomel & Sole, 2017). Participants started PC exercise with the barbell just above the patella's top edge (adjusted by wooden blocks), with the knees and hips slightly bent, shoulders above the barbell, flat back, and arms extended with the elbows pointed out. Participants were asked to perform an explosive extension of the hips, knees, and ankles (plantar flexion) while concomitantly shrugging their shoulders to accelerate the barbell in a vertical motion (Suchomel, et al., 2014b). Then, the participants were asked to catch the barbell in the front rack position (the shoulders rotated and flexed ahead with the elbows up) (Suchomel & Sole, 2017), and after that, to complete the movement through a full extension of the hips and knees to reach the upright position, with the barbell in the front rack position. Finally, if the participant's upper thigh went below parallel to the floor in the instant of the catch, the attempt was considered unsuccessful (Suchomel, et al., 2014a).

Predicted 1RM test

Initially, participants performed a general warm-up on a cycle ergometer at 20 km·h^{-1} for 5-min. After a 1-min rest, they performed a specific warm-up constituting of two sets of four PC repetitions at 45% 1RM, with a 2-min rest between the sets. Three minutes after the specific warm-up, participants performed the PC using the same technical parameters applied in the actual 1RM test.

The PC was performed with five different loads (30%, 45%, 60%, 75%, and 90% 1RM) in a randomized order. For loads of 30%, 45%, 60%, and 75% 1RM, a set of three repetitions was performed, while at 90% 1RM, only two repetitions were performed (Comfort, Allen, & Graham-Smith, 2011; Suchomel, et al., 2014b). A 30-second and 2-min rest intervals were allowed between the repetitions and loads, respectively. Participants were instructed to perform all repetitions as fast as possible and with maximum effort intention (Banyard, et al., 2017; Garcia-Ramos, et al., 2018a). Only the fastest repetition was used to predict the 1RM value, as the fastest repetition may be more representative of maximal performance when compared to the average.

Data collection

The video recordings of all PC repetitions were obtained via an iPhone 5S camera (Apple Inc., USA) and were filmed with 1,280 x 720-pixel resolution at 120 fps (Garhammer & Newton, 2013). Throughout all video recordings, the iPhone's camera was placed on a tripod 1.30 m above the ground, in the sagittal plane (participants' left side) at 5-m from the area in which the PC exercise was performed. A black background and a reflective marker placed on the left side of the Olympic barbell were used to allow better contrast and, consequently, accuracy in the auto-tracking of the barbell trajectory.

Barbell trajectory auto-tracking analysis was carried out using Kinovea software (Experimental Version 0.8.25-x64) (Daehlin, Krosshaug, & Chiu, 2017; Marriner, Cronin, Macadam, & Storey, 2017). Kinovea is a portable and easy-to-use tool which requires no experience to obtain accurate and reliable measurements, and has been used to evaluate different sport tasks (Balsalobre-Fernandez, Geiser, Krzyszkowski, & Kipp, 2020; Pueo, Penichet-Tomas, & Jimenez-Olmedo, 2020). For vertical velocity during the countermovement jump, Kinovea has shown strong association and low standard error of estimate when compared to gold-standard (three-dimensional motion capture system) ($r = 0.98$, standard error of estimate = 0.040 $m \cdot s^{-1}$, confidence interval = 0.037 to 0.043 $m \cdot s^{-1}$) (Pueo, et al., 2020). For the correct measurement, each video analysis was calibrated with the same reference length (weight plate of 45 cm diameter) and by the same investigator (Garhammer & Newton, 2013). After this step, an auto-tracking procedure was performed for all repetitions. The start of the PC movement was defined when the weight plates were resting on the wooden blocks, while the end of the movement was defined as the first negative peak vertical barbell velocity that occurred after the start of the lift (Balsalobre-Fernandez, et al., 2020). It is important to mention that the barbell was supported on the blocks to ensure the same barbell displacement in all repetitions and across the loads. Finally, barbell peak vertical velocity was obtained from the vertical axis (y-axis) in *xlsx files for subsequent statistical analysis. Only the repetition with the barbell highest peak vertical velocity at each load was considered for statistical analysis. For concentric-only exercise, the use of peak velocity is considered appropriate as it presents a similar load-velocity relationship result to the mean velocity and the mean propulsive velocity (Garcia-Ramos, Pestaña-Melero, Pérez-Castilla, Rojas, & Haff, 2018b).

Statistical analyses

The statistical analyses were performed using IBM SPSS v.21 software (IBM, New York, NY, USA) and own custom Excel spreadsheet (typical error [TE] and coefficient of variation [CV]). The first procedure applied was the Shapiro-Wilk's test to verify normal distribution. Then, the barbell peak vertical velocity was estimated at 1RM (100%) for each participant. After that, an individualized linear regression equation between the barbell peak vertical velocity and each of the five submaximal loads (30%, 45%, 60%, 75%, and 90% PC 1RM) was developed. Thereafter, a second linear regression was carried out to predict the 1RM value. The barbell peak vertical velocity value at 100% 1RM was used in the linear regression equation to predict the 1RM value. Moreover, the linear regression equation to predict the 1RM value was assessed by the coefficient of determination (R^2) and the associated 95% confidence interval (CI) and p-value. The significance level was set at $p \leq .05$.

To determine validity, the highest value of the two actual 1RM tests was compared to the predicted 1RM test of sessions 1 and 2. Validity was assessed using typical error (TE), coefficient of variation (CV) (Hopkins, 2000), effect size (ES), and the associated 95% CI (Nakagawa & Cuthill, 2007). ES were interpreted as: trivial (0 to ≤ 0.19), small (0.20 to 0.59), moderate (0.60 to 1.19), and large (1.20 to 1.99) based on previous guidelines (Hopkins, Marshall, Batterham, & Hanin, 2009). However, if the CI overlapped thresholds for positive and negative values, the effect was considered unclear (Nakagawa & Cuthill, 2007). Also, Bland-Altman plots (limits of agreement at 95% and bias) were used to evaluate the agreement of the 1RM value between the actual 1RM test (the highest value) and the two predicted tests (sessions 1 and 2) (Bland & Altman, 1986).

Between-session reliability was evaluated for the actual 1RM and predicted tests separately. For that, the intraclass correlation coefficient (ICC) and associated 95% CI were calculated and interpreted based on the recommendations of Cortina (1993) where ≥ 0.80 was highly reliable. In addition, TE and CV (Hopkins, 2000), ES and the associated 95% CI (Nakagawa & Cuthill, 2007), and Bland-Altman plots (limits of agreement at 95% and bias) were utilized (Bland & Altman, 1986).

Results

Shapiro-Wilk's test of normality revealed that all the data were normally distributed ($p > .05$). The estimated barbell peak vertical velocity at 100% for the PC was 1.87 ± 0.18 $m \cdot s^{-1}$ for session 1 and 1.86 ± 0.16 $m \cdot s^{-1}$ for session 2. The second linear regression equation was carried out between all the barbell peak vertical velocities and their respective loads. For session 1, R^2 was 0.62 (CI = 0.48 to 0.75) with $p < .01$. For session 2, R^2 was 0.45 (CI = 0.28 to 0.61) with $p < .01$ (Figure 1).

For validity, the results are presented in Table 1 and Figure 2. The highest actual 1RM test value was 65.2 ± 8.7 kg, while lower values were observed in the predicted 1RM test for sessions 1 (56.7 ± 8.3 kg) and 2 (53.5 ± 10.3 kg). Typical error (TE), CV (Table 1), and limits of agreement at 95% and bias (Figure 2) remained similar when the highest actual 1RM test value was compared to the predicted 1RM test of sessions 1 and 2. However, a lower ES was observed between the highest actual 1RM test value and the predicted 1RM test of session 1 (moderate)

Table 1. Validity analyses between the highest actual 1RM test value vs. predicted 1RM—sessions 1 and 2. Data presented as mean and (95% confidence interval)

	Highest 1RM test vs. predicted 1RM—Session 1	Highest 1RM test vs. predicted 1RM—Session 2
TE (kg)	5.00 (3.55, 8.50)	3.58 (2.54, 6.08)
CV (%)	8.21 (5.80, 14.00)	6.03 (4.30, 10.00)
ES	-1.00 (-1.56, -0.52)	-1.23 (-1.84, -0.71)

Note. TE = typical error, CV = coefficient of variation, ES = effect size.

Table 2. Reliability analyses between 1RM tests and predicted 1RM based on the load-velocity relationship

Tests	Session 1 (kg)	Session 2 (kg)	ICC	TE (kg)	CV (%)	ES
1RM test	62.08 ± 7.67	65.21 ± 8.69	0.94 (0.81 – 0.98)	2.14 (1.52 - 3.65)	3.37 (2.40 - 5.70)	0.38 (-0.04 - 0.83)
Predicted 1RM	56.70 ± 8.31	53.52 ± 10.29	0.69 (0.19 – 0.87)	5.34 (3.79 - 9.08)	9.69 (6.90 - 16.00)	-0.34 (-0.78 - 0.08)

Note. 1RM = one-repetition maximum, ICC = intraclass correlation coefficient, TE = typical error, CV = coefficient of variation, and ES = effect size. Sessions 1 and 2 = data presented as mean and standard deviation. ICC, TE, CV, and ES = data presented as mean and (confidence interval 95%).

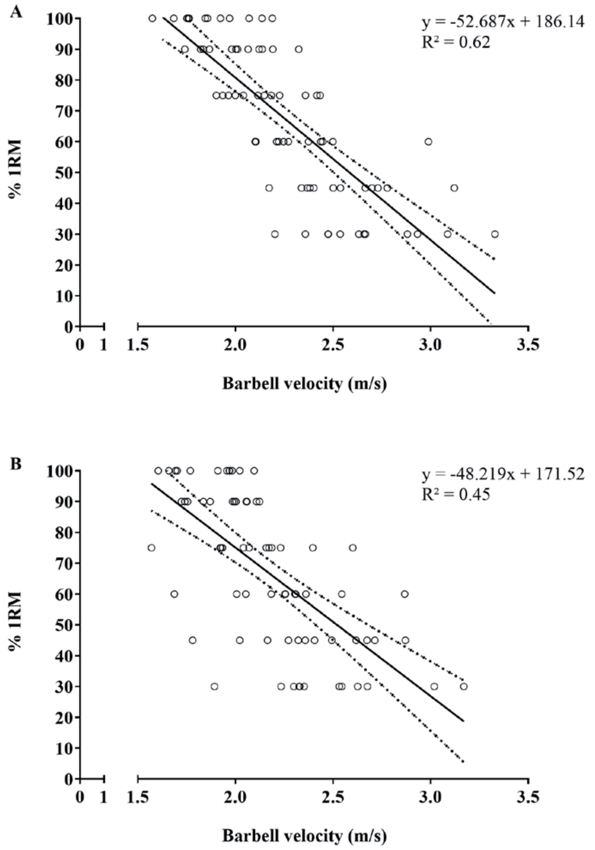

Figure 1. Relationship between bar-velocity and percentages of 1RM (30%, 45%, 60%, 75%, 90%, and 100% 1RM). (A) Session 1 and (B) Session 2. Dotted lines represent confidence interval (95%). R^2 = coefficient of determination.

when compared to the ES between the highest 1RM test value and the predicted 1RM test of session 2 (large) (Table 1).

Regarding reliability, the results are presented in Table 2 and Figure 3. The predicted 1RM presented lower reliability than the actual 1RM test due to lower ICC, higher TE, CV (Table 2), and width of limits of agreement at 95% (Figure 3).

Discussion and conclusions

The present study investigated the predictive validity and reliability of the load-velocity relationship for the prediction of 1RM value for the PC exercise. It was hypothesized that the load-velocity relationship would present high predictive validity and reliability. However, our hypothesis was not confirmed. Our findings revealed a low predictive validity of the load-velocity relationship to predict the 1RM value. Moreover, the predicted 1RM demonstrated inferior reliability compared to the actual 1RM test.

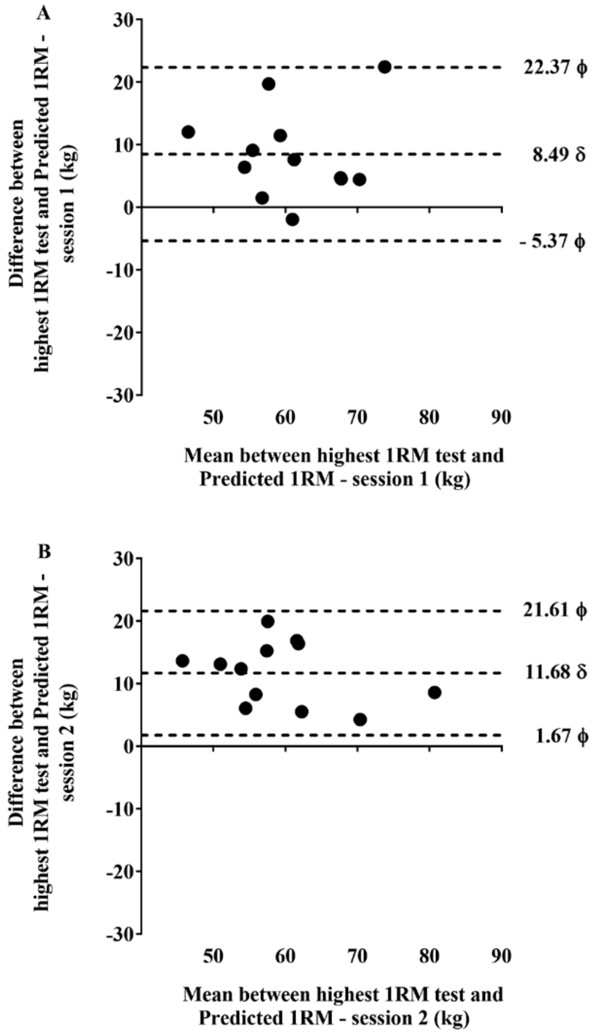

Figure 2. Validity analysis. Bland-Altman plots showing differences between the highest actual 1RM test value vs. predicted 1RM—Session 1 (A) and Session 2 (B). δ= bias; θ = superior and inferior limits of agreement.

The load-velocity relationship results are presented in Figure 1. Similar to the present study, Berton et al. (2021) also did not find a strong load-velocity relationship for PC (R^2 = 0.60 to 0.66); however, in the participants with weightlifting derivatives experience. On the other hand, the results with bench press and half-squat exercises demonstrated a strong load-velocity relationship (R^2 ≥ 0.94) (Loturco, et al., 2016, 2017; Perez-Castilla, et al., 2018). The explanation for these distinct results

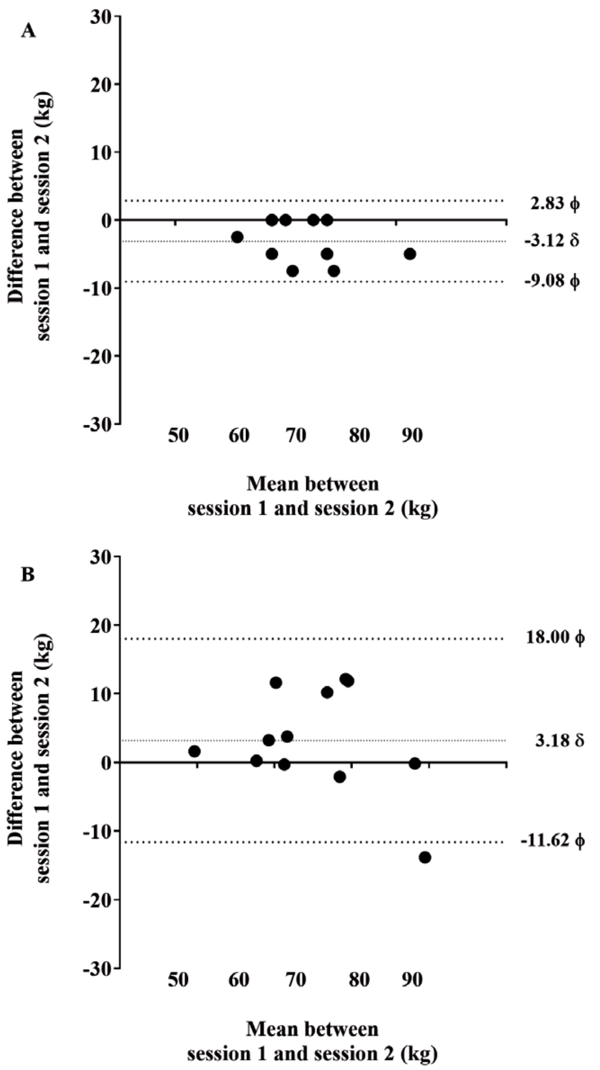

Figure 3. Reliability analysis. Bland-Altman plots showing differences between (A) 1RM tests—sessions 1 and 2, and (B) predicted 1RM—sessions 1 and 2. δ= bias, θ = superior and inferior limits of agreement.

(PC vs. bench press and squat) may be related to the higher technical complexity of the PC exercise. In other words, participants may not have acquired consistent PC technical standards. For example, they may not have completed the triple extension (i.e., the hip, knee, and ankle extension) due to the focus on the displacement under the barbell during the catch phase (DeWeese, et al., 2016; b). From this technical deficiency, they may not have achieved maximum velocity at each load; a factor that is relevant for a strong load-velocity relationship.

Another important result was the low validity with the highest actual 1RM test value and predicted 1RM values (Table 1, Figure 2). A similar result was observed, even in participants with weightlifting derivatives experience (TE = 3.9 to 4.5 kg and CV = 4.6 to 5.7%) (Berton, et al., 2021). In addition, low validity of the load-velocity relationship to predict the 1RM value can also be found in the deadlift exercise. Ruf et al. (2018) demonstrated large absolute (9.1 to 13.7 kg) and relative errors (3.3 to 5.3%) between the highest actual 1RM test values and the predicted 1RM values. On the other hand, the load-velocity relationship allowed a high validity for the bench press (relative error = 0.8 to 1.3%) (Loturco, et al., 2017) and half-squat exercises (relative error = 0.3 to 0.7%) (Loturco, et al., 2016). As can be observed, the accuracy and consequently, the validity of the load-velocity relationship to predict the 1RM values vary depending on the exercise. Although the reasons for the distinct results are not fully understood, it may be hypothesized that one of the factors is the technical complexity of the exercises. Corroborating to this logic, exercises of high technical complexity (PC and deadlift) (Ruf, et al., 2018) present lower validity compared to exercises of less technical complexity (bench press and half-squat on a Smith-machine) (Loturco, et al., 2016, 2017).

Reliability is another critical factor in performing tests (Hopkins, 2000). High reliability allows us to verify small changes induced during the training program (Hopkins, 2000). From this perspective, our results evidenced lower reliability of the predicted 1RM values than the actual 1RM test (Table 2, Figure 3). The present study findings are consistent with some results in the literature (Banyard, et al., 2017; Garcia-Ramos, et al., 2018; Ruf, et al., 2018). For example, Berton et al. (2021) also showed inferior reliability for the predicted 1RM compared to the actual 1RM test in the PC exercise (CV = 4.8% and 3.4%, respectively). Garcia-Ramos et al. (2018a) demonstrated lower reliability for the predicted 1RM compared to the actual 1RM test in the bench press exercise (CV = 3.0% and 1.8%, respectively). In addition, Banyard et al. (2017) also showed higher CVs (5.7 to 12.2%) for predicted 1RM sessions compared to the actual 1RM test (2.1%) in the deep back squat exercise. From these results, it becomes evident that the predicted 1RM value based on the load-velocity relationship is not the best option to verify small changes in the 1RM value.

This study is not without limitations. First, the present study did not use three-dimensional motion capture, the gold standard for image analysis (Lorenzetti, Lamparter, & Luthy, 2017; Sato, et al., 2015). Although a limitation, from a practical standpoint, few strength and conditioning coaches have access to this type of equipment. Thus, the data collected by a smartphone and the use of free software may favor implementation and usability. Second, only two prediction 1RM sessions were performed, further improving applicability. Specifically, including more sessions could induce a technical improvement in the PC and, consequently, provide a better predicted 1RM value. However, due to high time demand, several 1RM testing sessions may be impractical in training programs.

In conclusion, the present study demonstrated that the load-velocity relationship provides low validity to predict the 1RM value in the PC exercise. Furthermore, the predicted 1RM presented inferior reliability compared to the actual 1RM test in men with no experience in the PC exercise. These results collectively support the use of the 1RM test instead of the load-velocity relationship to measure the 1RM value in the PC exercise.

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