Title Page

Validity of different velocity-based methods and repetitions-to-failure equations for predicting the one-repetition maximum during two upper-body pulling exercises

Running head: Velocity vs. repetitions-to failure to predict 1RM

Authors: Alejandro Pérez-Castilla,[1] Dejan Suzovic,[2] Aleksandra Domanovic,[2] John F. T. Fernandes,[3] Amador García-Ramos,[1,4]

Institutional Affiliations:

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

[2] The Research Centre, Faculty of Sport and Physical Education, University of Belgrade, Belgrade, Serbia.

[3] Sport, Exercise and Well-being Arena, Hartpury University, Hartpury, United Kingdom.

[4] Department of Sports Sciences and Physical Conditioning, Faculty of Education, CIEDE, Catholic University of the Most Holy Concepción, Chile.

Corresponding author:

Amador García-Ramos, PhD. Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Spain. Department of Sports Sciences and Physical Conditioning, Faculty of Education, CIEDE, Catholic University of the Most Holy Concepción, Chile. Tel.: +34 677815348. E-mail: amagr@ugr.es

Acknowledgments:

The present study was conducted at the laboratory lead by Dr. Slobodan Jaric, who passed away during the writing process of this paper. We wish to thank Dr. Slobodan Jaric for inspiring our past, present and future research work. This study was supported by the University of Granada under a postdoctoral grant (perfeccionamiento de doctores) awarded to AGR and by the Spanish Ministry of Education, Culture and Sport under a pre-doctoral grant (FPU15/03649) awarded to APC.

Validity of different velocity-based methods and repetitions-to-failure equations for predicting the one-repetition maximum during two upper-body pulling exercises

ABSTRACT

This study aimed to compare the accuracy of different velocity-based methods and repetitions-to-failure equations for predicting the one-repetition maximum (i.e., maximum load that can be lifted once; 1RM) during two upper-body pulling exercises. Twenty-three men were tested in two sessions during the lat pulldown and seated cable row exercises. Each session consisted of an incremental loading test until reaching the 1RM followed by a set of repetitions-to-failure against the 80%1RM load. The 1RM was estimated from the individual load-velocity relationships modelled through four (~40, 55, 70, and 85%1RM; multiple-point method) or two loads (~40 and 85%1RM; two-point method). Mean velocity was recorded with a linear position transducer and a smartphone application. Therefore, four velocity-based methods were used as a result of combining the two devices and the two methods. Two repetitions-to-failure equations (Mayhew and Wathan) were also used to predict the 1RM from the load and number of repetitions completed. The absolute differences with respect to the actual 1RM were higher for the repetitions-to-failure equations than velocity-based methods during the seated cable row exercise (P=0.004), but not for the lat pulldown exercise (P=0.200). The repetitions-to-failure equations significantly underestimated the actual 1RM (P<0.05; range: -6.65 to -2.14 kg), while no systematic differences were observed for the velocity-based methods (range: -1.75 to 1.65 kg). All predicted 1RMs were highly correlated with the actual 1RM ($r \geq 0.96$). The velocity-based methods provide a more accurate estimate of the 1RM than the Mayhew and Wathan repetitions-to-failure equations during the lat pulldown and seated cable row exercises.

Keywords: maximum dynamic strength; lat pulldown; seated cable row; linear position transducer; smartphone application.

INTRODUCTION

The one-repetition maximum (1RM), defined as the maximum load that can be lifted once, is frequently used to evaluate an individual's maximal dynamic strength as well as to prescribe the loads during resistance training programs (5,7). However, the direct determination of the 1RM has been frequently discouraged because it is a time consuming procedure, that is both physically and psychologically demanding (10,19). As a result, several indirect methods have been proposed to predict the 1RM (15,32). One such method consists of regression equations that estimate the 1RM from the maximal number of repetitions performed with a submaximal load (i.e., repetitions-to-failure equations) (23). Although several repetitions-to-failure equations are commonly used in practice (e.g., Brzycki, Mayhew, Wathan, etc.) (28), only few studies have examined their cross-validation to other populations and exercises (16,30,32). Whilst repetitions-to-failure equations have the advantage that no sophisticated equipment (e.g., a linear position transducer) is needed to estimate the 1RM (23), their accuracy may be influenced by several factors such as the amount of repetitions performed, the type of exercise, lifting tempo, subjects' training history and sex (6,27,32). Moreover, since performing repetitions until muscular failure may induce an excessive fatigue that can create an interference with the training goals (22), a less prone to fatigue method based on movement velocity has recently gained popularity in the strength and conditioning field (15). However, to our knowledge, no study has compared the accuracy in the prediction of the 1RM between the novel velocity-based method and the repetitions-to-failure equations.

The linear relationship between the load and movement velocity has been used to predict the 1RM during many resistance training exercises (13,24). The modelling of the individual load-velocity relationship has typically consisted of the assessment of velocity outputs under multiple submaximal loads (usually between 4 and 9 loads) (3,21).

Consequently, the 1RM can be estimated by a linear regression as the load associated with the velocity of the 1RM (V1RM) (3,10,26). This approach has been referred to as the "multiple-point method" (12). Given the linearity of the load-velocity relationship, it has been recently proposed that this relationship could be accurately modelled from two loads (i.e., "two-point method") (10,12). Notably, the two-point method is a quicker and less prone to fatigue procedure of predicting 1RM (12). However, the accuracy of the two-point method for predicting the 1RM has only been confirmed for the bench press performed in a Smith machine (10). Indeed, a wide variety of exercises (e.g., upper-body pulling exercises) are used in research and the applied setting (9,13). Therefore, in order to give researchers and applied practitioners confidence, the feasibility of the two-point method to predict the 1RM should be confirmed in other resistance training exercises.

Numerous devices can be currently used to monitor movement velocity during resistance training exercises (1,4). The linear position transducer (LPT) has been the most used device in scientific research (1,2,13,20). However, the relatively high cost (~2,000 US dollars) and poor versatility (i.e., the requirement of a cable attachment and PC software) may limit its application outside laboratory or applied setting (1). This has encouraged the development of more practical devices such as accelerometers or smartphone applications (2,20). Recently, when compared to a LPT, a smartphone application named "Powerlift" has been deemed a valid tool to monitor barbell's velocity during a variety of resistance training exercises such as the bench press, full-squat and hip-thrust (1,2). The validity of Powerlift to estimate the 1RM has only been examined during the bench press exercise (2). For the applied practitioners to use Powerlift during other basic resistance training exercises (e.g., upper-body pulling exercises) its validity must first be determined.

To address the gaps in the literature, we sought to determine if vertical and horizontal upper-body pulling 1RM could be predicted from four velocity-based methods (i.e., multiple-point and two-point methods using the LPT and Powerlift) and two generic repetitions-to-failure equations (i.e., Mayhew and Wathan). Consequently, the aim of the study was to compare the accuracy of different velocity-based methods and repetitions-to-failure equations when estimating the 1RM during the lat pulldown and seated cable row exercises. Due to the paucity of similar studies, no specific hypothesis regarding the possible differences in the accuracy of velocity-based methods and repetitions-to-failure equations for estimating the 1RM was formulated.

METHODS

Experimental approach to the problem

A randomized crossover design was used to compare the precision of different velocity-based methods and repetitions-to-failure equations for predicting the lat pulldown and seated cable row 1RM. Subjects were tested on two sessions separated by 48-72 hours. One exercise was evaluated in each testing session. At the beginning of each session subjects were familiarized with the lat pulldown or seated cable row exercises. Thereafter each session consisted of an incremental loading test until reaching the 1RM followed by a set of repetitions-to-failure against the 80%1RM load. Six different prediction methods were examined in the present study: four based on movement velocity and two based on repetitions-to-failure equations:

- *Velocity-based methods*: The mean velocity of all the repetitions performed during the incremental loading test was simultaneously recorded by a LPT and Powerlift. The data of four loads (~40, 55, 70 and 85% of 1RM; i.e., multiple-point method) or only two loads (~40 and 85% of 1RM; i.e., two-point method) were used for the modelling of the individual load-velocity relationships by linear regression. Therefore, the four velocity-based prediction methods consisted of the combination of the two devices (LPT and Powerlift) and the two methods (multiple-point and two-point). The 1RM was estimated from the individual load-velocity relationships as the load associated with the V1RM (3,13). The following V1RM values were used to estimate the 1RM: lat pulldown measured with the LPT and Powerlift = 0.47 ± 0.04 and 0.52 ± 0.06 $m \cdot s^{-1}$, respectively, and for the seated cable row measured with the LPT and Powerlift = 0.40 ± 0.05 and 0.53 ± 0.07 $m \cdot s^{-1}$, respectively.

- *Repetitions-to-failure equations*: The Mayhew et al. (17) (1RM = [submaximal load / 52.2 + $41.9 \cdot e^{-0.055 \cdot \text{repetitions}}$]/ 100) and Wathan (31) (1RM = [submaximal load / 48.8 + $53.8 \cdot e^{-0.075 \cdot \text{repetitions}}$] / 100) equations were used to predict the 1RM from the load (kg) and the number of repetitions completed.

Subjects

Twenty-three collegiate sport sciences students, 12 men (age = 20.8 ± 2.5 years, body mass = 78.9 ± 10.7 kg, body height 179.6 ± 6.1 cm, lat pulldown 1RM = 78.1 ± 14.0 kg, seated cable row 1RM = 74.4 ± 14.2 kg) and 11 women (age = 20.2 ± 1.1 years, body mass = 65.3 ± 4.4 kg, body height 172.2 ± 4.9 cm, lat pulldown 1RM = 46.1 ± 7.3 kg, seated cable row 1RM = 44.1 ± 6.2 kg), volunteered to participate in this study. All subjects were physically active and did not report any physical limitation that could compromise performance during the tested exercises. They were informed of the study procedures and signed a written informed consent form prior to initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board.

Procedures

The testing sessions began with a standardised warm-up comprising of dynamic upper-body mobilization exercises followed by 1 set of 5 repetitions performed in a controlled manner against an external load of 10 kg in the tested exercise. The displacement of the concentric phase was measured with a LPT during the 5 warm-up repetitions and the average value of the 5 repetitions was used to determine the individual range of motion (0.60 ± 0.05 m in the lat pulldown and 0.40 ± 0.05 m in the seated cable row). After warming-up, subjects rested for 5 min and then they completed an incremental loading test followed by a set of repetitions to failure. The incremental loading test and the set of repetition-to-failure were separated by 10 min.

- *Incremental loading test:* The initial external load was set at 20 kg for men and 10 kg for women in both exercises. The load was progressively increased in 10 kg for men and 5 kg for women until the mean velocity recorded by the LPT was lower than 0.60 $m{\cdot}s^{-1}$. Afterwards, the load was increased in increments of 1 to 5 kg for men and 1 to 2.5 kg for women until the subjects failed one repetition. The 1RM was defined as the maximum load (kg) that was lifted through the whole range of motion individually measured during the warm-up set. Two trials were executed when the mean velocity was higher than 0.60 $m{\cdot}s^{-1}$ and only one for the heavier loads (≤ 0.60 ms^{-1}). In our pilot testing we observed that the mean velocity of the 1RM trial in both exercises was about 0.50 $m{\cdot}s^{-1}$, thus a mean velocity of 0.60 $m{\cdot}s^{-1}$ was used. Only the trial with the highest mean velocity was selected for further analysis. Intra-set rest was 15 s and inter-set rest was fixed to 5 min. Subjects received velocity performance feedback immediately after each repetition to encourage them to perform all repetitions at the maximal intended velocity. The average number of loads tested was 6.3 ± 1.3 and 5.9 ± 1.5 for the lat pulldown and seated cable row exercises, respectively.

- *Repetitions-to-failure test:* Subjects performed one set of repetitions-to-failure using approximately the 80% of their previously determined 1RM. They performed the concentric phase at the maximum intended velocity and the eccentric phase under control (32). The repetitions-to-failure assessment ended when the subjects were unable to perform a repetition with a proper technique or when the predefined range of motion was not reached. The average number of repetitions performed were 11.3 ± 3.2 and 9.5 ± 3.5 for the lat pulldown and seated cable row exercises, respectively.

Description of the exercises

- *Lat pulldown*: Subjects sat on the bench of a custom-made lat machine with feet flat on the floor, the spine in a neutral position with slight backward lean (~100º of hips flexion), and the arms fully extended overhead with a pronated grip slightly wider than shoulder width apart. From this initial position, subjects were instructed to pull the bar downward as fast as possible in front of the body without any extension of the trunk. The range of motion was defined as the distance recorded by the LPT from the initial position until the bar reached the level of the chin. The bench of the lat machine was individually adjusted to ensure a comfortable position and the knees were secured with the kneepad (29).

- *Seated cable* row: Subjects sat on the seat of a custom-made row machine with their feet on the footplates and a self-selected knee flexion, the trunk in an upright position, and the arms fully extended with a neutral grip using a v-bar (8). From that position, subjects pulled the v-bar as fast as possible towards their sternum until their wrists touched the rib cage without any flexion or extension of the trunk. The range of motion was defined as the distance recorded by the LPT from the initial position until the wrists of touched the rib cage.

Velocity measurements

The mean velocity used to determine the individual load-velocity relationships was recorded during the incremental loading test by two commercially available devices:

-*Linear position transducer* (Real Power Pro Globus, Codogne, Italy): an isoinertial dynamometer which consists of a cable-extension LPT interfaced with a personal computer and a custom software through an USB port (11,18). The displacement-time data were recorded at a sampling rate of 1,000 Hz. The mean velocity was determined by the differentiation of the displacement data with respect to time from the start of the concentric phase until the end of the range of motion was reached. The cord of the LPT was vertically attached to the first weight plate of the lat pulldown and seated cable row machines.

-*Smartphone application*: Powerlift (version 6.0.1) was installed on an iPhone 8 Plus running iOS 11 (iPhone, Apple Inc., California, USA) which has a recording frequency of 240 frames per second at a quality of 720 pixels. The high accuracy of Powerlift to measure mean velocity during the bench press, full-squat and hip-thrust exercises has been reported in detail elsewhere (1). Powerlift was designed to assess mean velocity by the frame-by-frame manual inspection of a slow motion video recording by the smartphone high-speed camera (2). Specifically, the mean velocity was calculated as the displacement indicated in the application (i.e., the subject's range of motion) divided by the lifting duration (i.e., the time between initial and final frames selected by the user). The iPhone 8 Plus was held by a researcher in portrait position and recorded the first weight plate of the machine at 1.5 m. The initial frame was identified as the first instant in which the first weight plate started its upward movement, while the final frame was the moment in which the first weight plate reached a black tape that was positioned at the end of the subject's range of motion

Statistical analysis

Data are presented as means and standard deviations (SD). The normal distribution of the data was confirmed by the Shapiro-Wilk test ($P > 0.05$). A two-factor mixed ANOVA, with the "prediction method" as within-subjects factor and "sex" as between-subjects factor, was applied on the absolute differences between the actual and predicted 1RM separately for each exercise. The Greenhouse-Geisser correction was used when the Mauchly's sphericity test was violated and pairwise differences were identified using Bonferroni post-hoc corrections. The validity of the predicted 1RM methods with respect to the actual 1RM was also examined through paired samples *t*-tests, the Hedge's *g* effect size (ES), the Pearson's correlation coefficient (*r*), the standard error of the estimate (SEE), and Bland-Altman plots. The strength of the *r* coefficients was interpreted as follows: *trivial* (< 0.1), *small* (0.1-0.3), *moderate* (0.3-0.5), *high* (0.5-0.7), *very high* (0.7-0.9) or *practically perfect* (> 0.9) (14). The magnitude of the ES was interpreted as follows: *trivial* (< 0.2), *small* (0.2-0.6), *moderate* (0.6-1.2), *large* (1.2-2.0) and *very large* (> 2.0) (14). Statistical analyses were performed using the software package SPSS (version 22.0: SPSS, Ins., Chicago, IL, USA). Alpha was set at $P < 0.05$ level.

RESULTS

A significant main effect was observed for the prediction method in the seated cable row exercise (F = 7.60, $P = 0.004$) due to lower absolute differences respect to the actual 1RM for the velocity-based methods compared to the repetitions-to-failure equations, but not in the lat pulldown exercise (F = 1.61, $P = 0.200$) (Figure 1). The absolute differences respect to the actual 1RM was lower for women compared to men (lat pulldown: F = 9.28, $P = 0.006$; seated cable row: F = 8.61 $P = 0.008$). Neither of the interactions (prediction method × sex) reached statistical significance (lat pulldown: F = 0.37, $P = 0.750$; seated cable row: F = 2.24 $P = 0.135$).

****Figure 1 near here****

Both repetitions-to-failure equations significantly underestimated the actual 1RM during both exercises ($P < 0.05$; ES range: -0.10 to -0.32), while no significant differences were observed for the velocity-based methods ($P > 0.05$; ES range: -0.08 to 0.09). All predicted 1RMs were highly correlated with the actual 1RM ($r \geq 0.96$) and presented moderate random errors (SEE ≤ 5.44 kg) in the lat pulldown (Figure 2) and seated cable row exercises (Figure 3). The Bland-Altman plots showed slightly higher systematic bias for the repetitions-to-failure equations compared to the velocity-based methods during both the lat pulldown (range: -4.51 to -2.14 kg *vs.* -1.75 to -0.65 kg; Figure 4) and seated cable row exercises (range: -6.75 to -5.20 kg *vs.* -0.02 to 1.65 kg; Figure 5). Finally, the random error was comparable for all the prediction methods (range: 2.98 to 6.89 kg).

****Figure 2 near here****

****Figure 3 near here****

****Figure 4 near here****

****Figure 5 near here****

DISCUSSION

The aim of the study was to compare the accuracy of different velocity-based methods and repetitions-to-failure equations when estimating the 1RM during the lat pulldown and seated cable row exercises. Although all the examined prediction methods were able to estimate the

1RM with an acceptable precision, the velocity-based methods provided a more accurate prediction of the 1RM compared to the repetitions-to-failure equations. Note that both repetitions-to-failure equations systematically underestimated the actual 1RM, while the absolute differences respect to the actual 1RM was significantly higher for the repetitions-to-failure equations during the seated cable row exercise. The precision in the estimation of the 1RM did not meaningfully differ between the four velocity-based methods. Therefore, the most practical velocity-based procedure (i.e., fatigue-free and cost-effective) to estimate the 1RM would consist of the application of the two-point method and the assessment of movement velocity with Powerlift.

Numerous studies have been conducted to establish the relationship between the relative loads (%1RM) and the number of repetitions to failure in an attempt to improve the prescription of loads during resistance training programs (16,23,30,32). Although the accuracy of the repetitions-to-failure equations could be compromised by several factors (6,27,32), they are commonly used in the strength and conditioning field (28,32). LeSeur et al. (16) examined the accuracy of seven repetitions-to-failure equations in untrained college students, suggesting that the Mayhew and Wathan equations were the most accurate for predicting the bench press 1RM, the Wathan equation the most accurate for predicting the squat 1RM, and none of the examined equations revealed an acceptable accuracy for predicting the deadlift 1RM. Similarly, Wood et al. (32) showed that Mayhew, Epley and Wathan equations were the most accurate to estimate the 1RM in sedentary older adults during 10 resistance training exercises performed on machine weight devices compared to other commonly used repetitions-to-failure equations. In contrast, Ware et al. (30) concluded that none of the four repetitions-to-failure equations examined in Division II college football players was accurate to predict the squat and bench press 1RM. The results of the present study generally support the use of the Mayhew and Wathan equations to estimate the 1RM during the lat pulldown and seated cable row exercises. However, it should be kept in mind that performing repetitions until muscular failure might impair long-term adaptations in explosive actions that are related to athletic performance (e.g., jump and sprint performance) (22) and could even compromise the training volume prescribed for a session (25).

A less fatiguing method of predicting the 1RM consists of the assessment of movement velocity against submaximal loads (13,15). This is the first study that has shown that the velocity-based methods can provide a slightly more accurate estimate of the 1RM than the repetitions-to-failure equations. Despite these findings, the evidence to support these velocity-based 1RM prediction methods is controversial in the scientific literature. For example, Banyard et al. (3) and Ruf et al. (26) found that the predicted 1RMs computed from 3 to 5 submaximal loads (ranging from 20%1RM and 90%1RM) substantially overestimated the actual 1RM in the full depth free-weight back squat (absolute error range: 10.6 to 17.2 kg) and deadlift (absolute error range: 9.1 to 13.7 kg) exercises, respectively. On the other hand, in line with the results of this study, Garcia-Ramos et al. (10) reported that the 1RM can be estimated with a high accuracy (systematic bias range: -2.3 to 0.5 kg) from the individual load-velocity relationship using the mean velocity recorded under only 2 loads (~50%1RM and 80%1RM) during the bench press exercise performed in a Smith machine. Although further studies are needed to explain the differences between the studies mentioned above, the differences in findings might be owing to the exercises used (i.e., machine-guided exercises *vs.* free-weight exercises), the V1RM values selected (i.e., standardised *vs.* the individual; note that the V1RM is not a reliable measure) (3,26), and extremity used (i.e., upper-body exercises *vs.* more complex lower-body exercises).

The present study examined, for the first time, the load-velocity relationship during the lat pulldown and seated cable row exercises. Our results highlight that an accurate load-velocity relationship can be obtained in both exercises using either a LPT or the smartphone Powerlift application. It should be noted that Powerlift has already been validated to monitor barbell's velocity during the bench press, full-squat and hip-thrust exercises (1). In addition, Powerlift has also been considered a valid device to estimate the 1RM during the bench press exercise (2). In line with the findings of Balsalobre-Fernandez et al. (2), our results indicate that Powerlift can be confidently used to estimate the 1RM from the individual load-velocity relationship during the lat pulldown and seated cable row exercises.

In conclusion, the velocity-based methods examined in the present study provided a more accurate estimate of the 1RM than the Mayhew and Wathan repetitions-to-failure equations during the lat pulldown and seated cable row exercises. Therefore, the 1RM prediction method based on the individual load-velocity relationship should be recommended over the repetitions-to-failure equations not only because it is safer and less fatiguing, but also because it provides a more accurate estimate of the 1RM.

PRACTICAL APPLICATIONS

The estimation of the 1RM through the individual load-velocity relationship only requires three steps (12): (i) setting of the exercise-specific V1RM, (ii) recording of the mean velocity against at least two different external loads, and (iii) modelling of the individual load-velocity relationship and determining the 1RM as the load associated with the V1RM. The results of this study suggest that applied practitioners can estimate the 1RM with acceptable precision through the individual load-velocity relationship modelled from the mean velocity recorded against only two loads (~ 40%1RM and 85%1RM; two-point method) with a cost-effective smartphone application.

REFERENCES

1. Balsalobre-Fernandez, C, Marchante, D, Baz-Valle, E, Alonso-Molero, I, Jimenez, SL, and Munoz-Lopez, M. Analysis of wearable and smartphone-based technologies for the measurement of barbell velocity in different resistance training exercises. *Front Physiol* 8: 649, 2017.
2. Balsalobre-Fernández, C, Marchante, D, Muñoz-López, M, and Jiménez, SL. Validity and reliability of a novel iPhone app for the measurement of barbell velocity and 1RM on the bench-press exercise. *J Sports Sci* 36: 64–70, 2018.
3. Banyard, HG, Nosaka, K, and Haff, GG. Reliability and validity of the load–velocity relationship to predict the 1RM back squat. *J Strength Cond Res* 31: 1897–1904, 2017.
4. Banyard, HG, Nosaka, K, Sato, K, and Haff, GG. Validity of various methods for determining velocity, force, and power in the back squat. *Int J Sports Physiol Perform* 12: 1170–1176, 2017.
5. Bird, SP, Tarpenning, KM, and Marino, FE. Designing resistance training programmes to enhance muscular fitness: A review of the acute programme variables. *Sports Med* 35: 841–851, 2005.
6. Braith, RW, Graves, JE, Leggett, SH, and Pollock, ML. Effect of training on the relationship between maximal and sub-maximal strength. *Med Sci Sports Exerc* 25: 132–138, 1993.
7. Buckner, SLS, Jessee, MBM, Mattocks, KKT, Mouser, JG, Counts, BR, Dankel, SJS, et al. Determining strength: a case for multiple methods of measurement. *Sports Med* 47: 193–195, 2017.

8. Cronin, JB, Jones, J V, and Hagstrom, JT. Kinematics and kinetics of the seated row and implications for conditioning. *J Strength Cond Res* 21: 1265–1270, 2007.

9. Fernandes, JFT, Lamb, KL, and Twist, C. A comparison of load-velocity and load-power relationships between well-trained young and middle-aged males during three popular resistance exercises. *J Strength Cond Res* 32: 1440–1447, 2018.

10. García-Ramos, A, Haff, G, Pestana-Melero, F, Perez-Castilla, A, Rojas, F, Balsalobre-Fernandez, C, et al. Feasibility of the two-point method for determining the one-repetition maximum in the bench press exercise. *Int J Sports Physiol Perform* 13: 474–481, 2018.

11. García-Ramos, A, Haff, GG, Padial, P, and Feriche, B. Reliability of power and velocity variables collected during the traditional and ballistic bench press exercise. *Sport Biomech* 17: 117–130, 2018.

12. Garcia-Ramos, A, Jaric, S, García-Ramos, A, and Jaric, S. Two-point method: a quick and fatigue-free procedure for assessment of muscle mechanical capacities and the one-repetition maximum. *Strength Cond J* 40: 54–66, 2018.

13. García-Ramos, A, Pestaña-Melero, FL, Pérez-Castilla, A, Rojas, FJ, and Haff, GG. Differences in the load-velocity profile between 4 bench press variants. *Int J Sports Physiol Perform* 13: 326–331, 2018.

14. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–13, 2009.

15. Hughes, LJ, Banyard, HG, Dempsey, AR, and Scott, BR. Using load-velocity relationships to predict 1rm in free-weight exercise. *J Strength Cond Res*. 2018. Epub ahead of print. doi: 10.1519/JSC.0000000000002550

16. LeSuer, DA, McCormick, JH, Mayhew, JL, Wasserstein, RL, and Arnold, MD. The accuracy of prediction equations for estimating 1-RM performance in the bench press,

squat, and deadlift. *J Strength Cond Res* 11: 211–213, 1997.

17. Mayhew, JL, Ball, TE, Arnold, MD, and Bowen, JC. Relative muscular endurance performance as a predictor of bench press strength in college men and women. *J Strength Cond Res* 6: 200–206, 1992.

18. Naclerio, F and Larumbe-Zabala, E. Loading intensity prediction from velocity and the OMNI-RES 0-10 scale in bench press. *J Strength Cond Res* 31: 323–329, 2017.

19. Niewiadomski, W, Laskowska, D, Gąsiorowska, A, Cybulski, G, Strasz, A, and Langfort, J. Determination and prediction of one repetition maximum (1RM): safety considerations. *J Hum Kinerics* 19: 109–120, 2008.

20. Orange, ST, Metcalfe, JW, Liefeith, A, Marshall, P, Madden, LA, Fewster, CR, et al. Validity and reliability of a wearable inertial sensor to measure velocity and power in the back squat and bench press. *J Strength Cond Res*. 2018. Epub ahead of print. doi: 10.1519/JSC.0000000000002574

21. Pallarés, JG, Sánchez-Medina, L, Pérez, CE, De La Cruz-Sánchez, E, and Mora-Rodriguez, R. Imposing a pause between the eccentric and concentric phases increases the reliability of isoinertial strength assessments. *J Sports Sci* 32: 1165–1175, 2014.

22. Pareja-Blanco, F, Rodríguez-Rosell, D, Sánchez-Medina, L, Sanchis-Moysi, J, Dorado, C, Mora-Custodio, R, et al. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scand J Med Sci Sports* 27: 724–735, 2016.

23. Pereira, M and Gomes, P. Muscular strength and endurance tests: reliability and prediction of one repetition maximum — Review and new evidences. *Rev Bras Med do Esporte* 9: 336–346, 2003.

24. Pérez-Castilla, A, García-Ramos, A, Padial, P, Morales-Artacho, AAJ, and Feriche, B. Load-velocity relationship in variations of the half-squat exercise: Influence of

execution technique. *J Strength Cond Res*. 2017. Epub ahead of print. doi: 10.1519/JSC.0000000000002072

25. Richmond, SR and Godard, MP. The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. *J Strength Cond Res* 18: 846–849, 2004.

26. Ruf, L, Chery, C, and Taylor, K-L. Validity and reliability of the load-velocity relationship to predict the one-repetition maximum in deadlift. *J Strength Cond Res* 32: 681–689, 2018.

27. Sakamoto, A and Sinclair, PJ. Effect of movement velocity on the relationship between training load and the number of repetitions of bench press. *J Strength Cond Res* 20: 523–527, 2006.

28. Sakamoto, A, Sinclair, PJ, and Naito, H. Strategies for maximizing power and strength gains in isoinertial resistance training: implications for competitive athletes. *J Phys Fit Sports Med* 5: 153–166, 2016.

29. Snarr, R, Eckert, RM, and Abbott, P. A Comparative analysis and technique of the lat pull-down. *Strength Cond J* 37: 21–25, 2015.

30. Ware, JS, Clemens, CT, Mayhew, JL, and Johnston, TJ. Muscular endurance repetitions to predict bench press and squat strength in college football players. *J Strength Cond Res* 9: 99–103, 1995.

31. Wathan, D. Essentials of strength training and conditioning. Champaign, IL: Human Kinetics, 1994.

32. Wood, TM, Maddalozzo, GF, and Harter, RA. Accuracy of seven equations for predicting 1-RM performance of apparently healthy, sedentary older adults. *Meas Phys Educ Exerc Sci* 6: 67–94, 2009.

FIGURE LEGEND

Figure 1. Comparison of the absolute differences between the actual one-repetition maximum (1RM) and the 1RM estimated from the different prediction methods in the lat pulldown (upper panel) and seated cable row (lower panel) exercises. Mean ± standard deviation are indicated. *, significant differences to Wathan; †, significant differences to Mayhew ($P < 0.05$, ANOVA with Bonferroni correction).

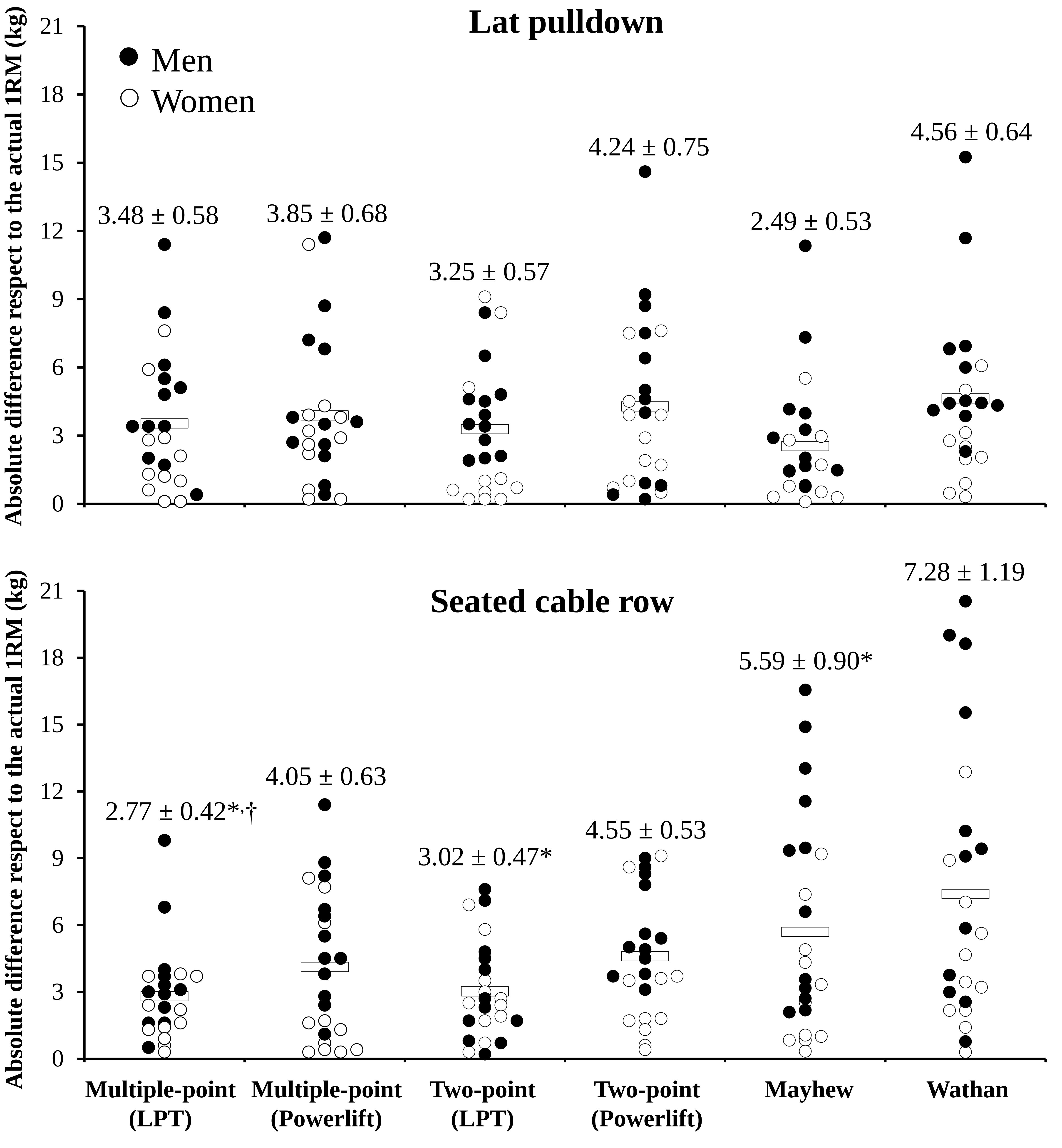
Figure 2. Relationship between the actual and predicted one-repetition maximum (1RM) obtained from the multiple-point method using a linear position transducer (LPT; upper-left panel) and Powerlift (upper-right panel), two-point method using a LPT (middle-left panel) and Powerlift (middle-right panel) and the repetitions-to-failure equations proposed by Mayhew (lower-left panel) and Watham (lower-right panel) in the lat pulldown exercise. The linear regression lines are shown with regression equations, correlation coefficients (*r*) and standard errors of estimate (SEE).

Figure 3. Relationship between the actual and predicted one-repetition maximum (1RM) obtained from the multiple-point method using a linear position transducer (LPT; upper-left panel) and Powerlift (upper-right panel), two-point method using a LPT (middle-left panel) and Powerlift (middle-right panel) and the repetitions-to-failure equations proposed by Mayhew (lower-left panel) and Watham (lower-right panel) in the seated cable row exercise. The linear regression lines are shown with regression equations, correlation coefficients (*r*) and standard errors of estimate (SEE).

Figure 4. Bland-Altman plots showing the differences between the actual and predicted one-repetition maximum (1RM) obtained from the multiple-point method using a linear position transducer (LPT; upper-left panel) and smartphone application (Powerlift; upper-right panel), two-point method using a LPT (middle-left panel) and Powerlift (middle-right panel) and the repetitions-to-failure equations proposed by Mayhew (lower-left panel) and Watham (lower-right panel) in the lat pulldown exercise. Each plot depicts the systematic bias and 95% limits of agreement (± 1.96 standard deviation; dashed lines), along with the regression line (solid line). The systematic bias ± random error together with strength of the relationship (r^2) and Hedge's *g* effect size (ES) are depicted in each plot. *, significant differences ($P < 0.05$; paired samples *t*-test).

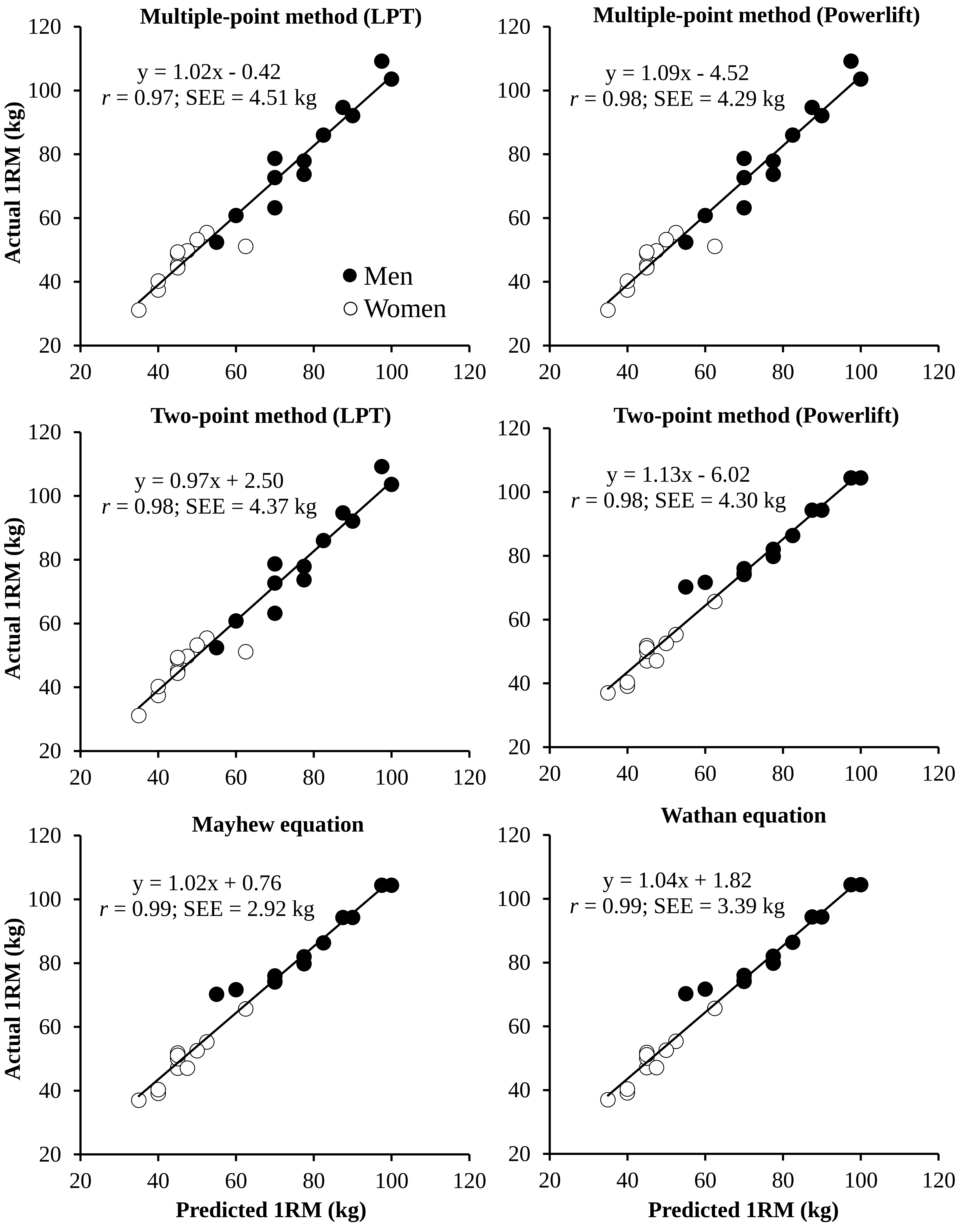
Figure 5. Bland-Altman plots showing the differences between the actual and predicted one-repetition maximum (1RM) obtained from the multiple-point method using a linear position transducer (LPT; upper-left panel) and smartphone application (Powerlift; upper-right panel), two-point method using a LPT (middle-left panel) and Powerlift (middle-right panel) and the repetitions-to-failure equations proposed by Mayhew (lower-left panel) and Watham (lower-right panel) in the seated cable row. Each plot depicts the systematic bias and 95% limits of agreement (± 1.96 standard deviation; dashed lines), along with the regression line (solid line). The systematic bias ± random error together with strength of the relationship (r^2) and Hedge's *g* effect size (ES) are depicted in each plot. *, significant differences ($P < 0.05$; paired samples *t*-test).

Figure 1



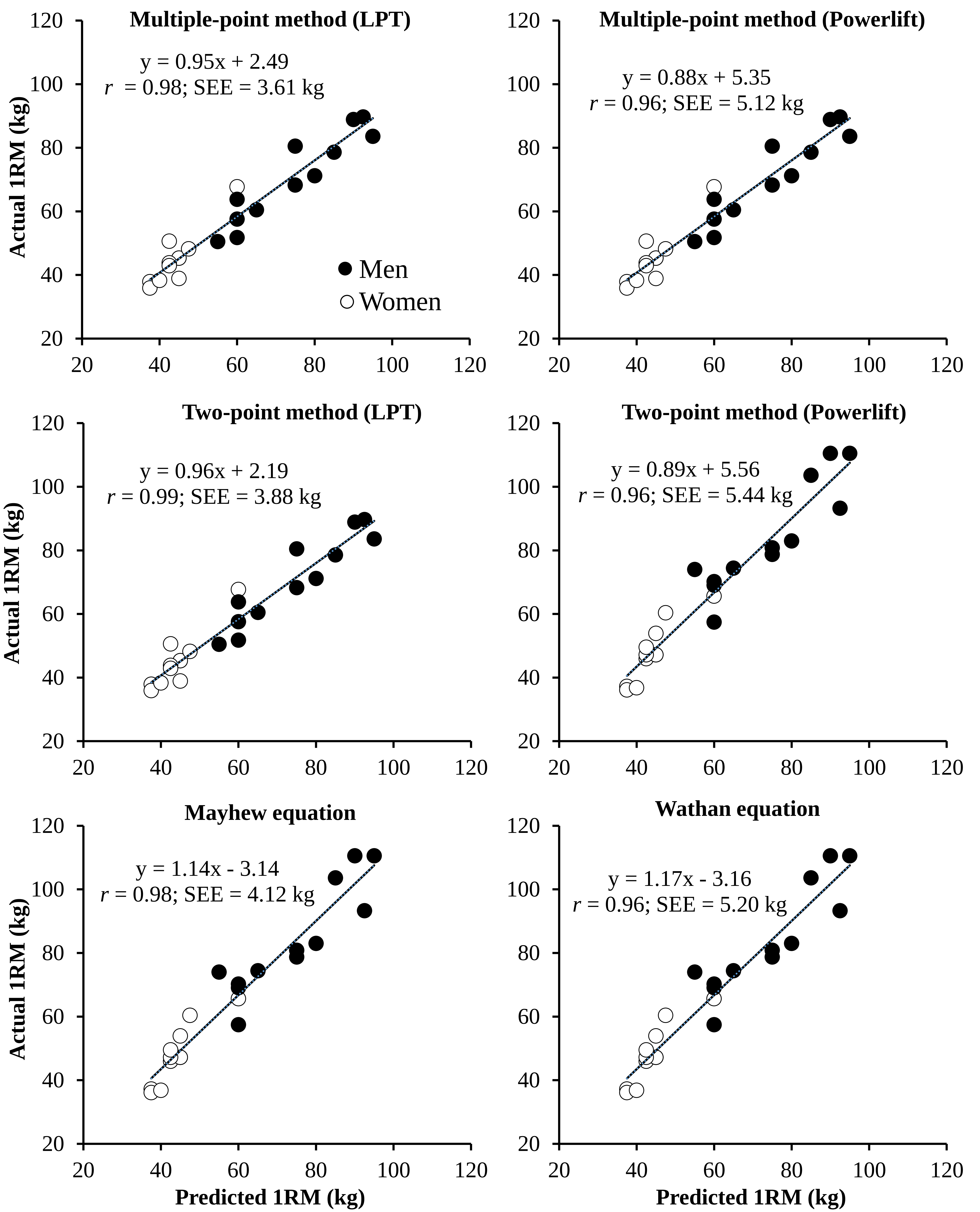
Lat pulldown
Men
Women
Absolute difference respect to the actual 1RM (kg)
0
3
6
9
12
15
18
21
3.48 ± 0.58
3.85 ± 0.68
3.25 ± 0.57
4.24 ± 0.75
2.49 ± 0.53
4.56 ± 0.64
Seated cable row
Absolute difference respect to the actual 1RM (kg)
2.77 ± 0.42*,†
4.05 ± 0.63
3.02 ± 0.47*
4.55 ± 0.53
5.59 ± 0.90*
7.28 ± 1.19
Multiple-point (LPT)
Multiple-point (Powerlift)
Two-point (LPT)
Two-point (Powerlift)
Mayhew
Wathan

Figure 2



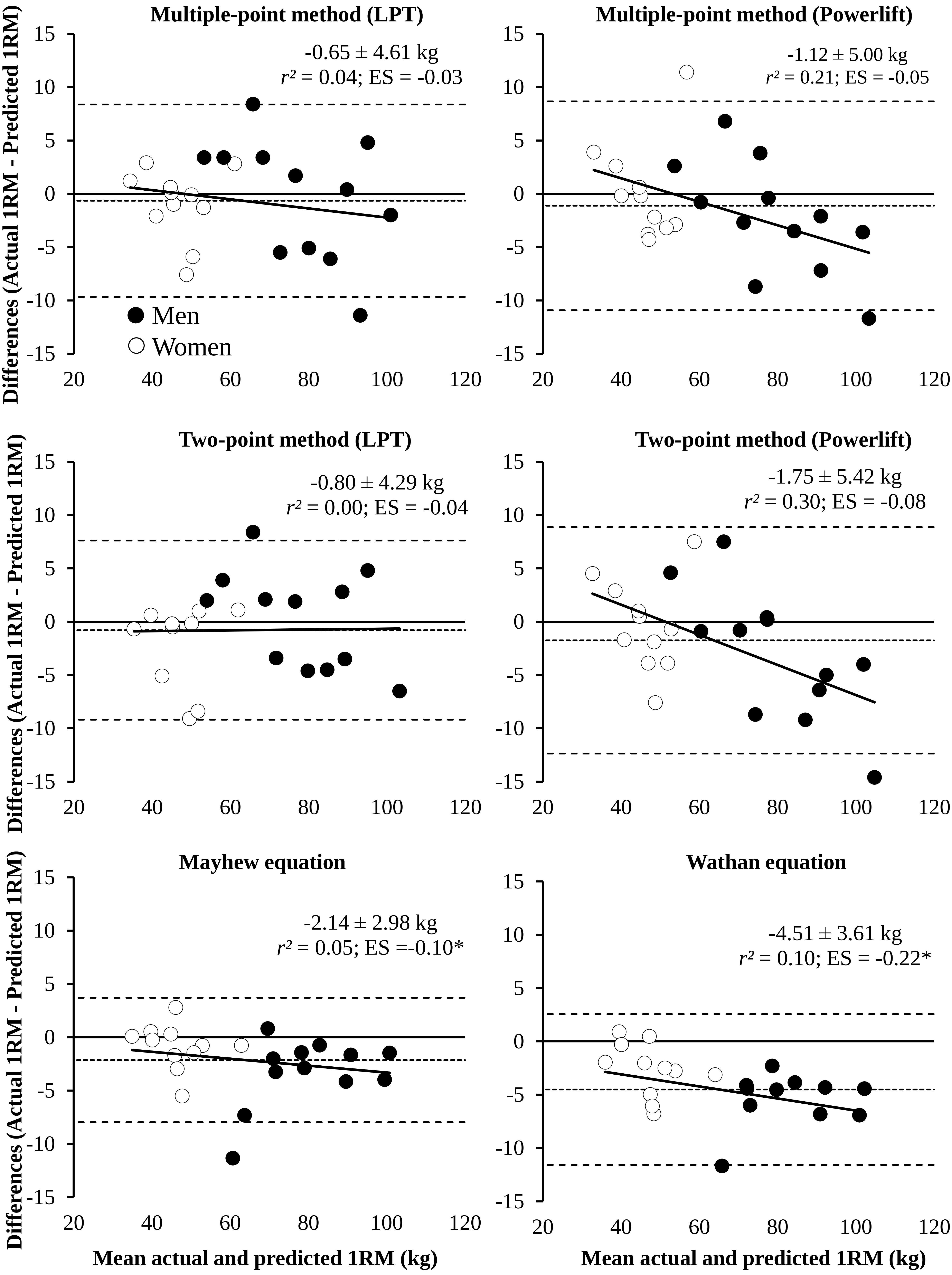
Multiple-point method (LPT)
y = 1.02x - 0.42
r = 0.97; SEE = 4.51 kg
Men
Women
Multiple-point method (Powerlift)
y = 1.09x - 4.52
r = 0.98; SEE = 4.29 kg
Two-point method (LPT)
y = 0.97x + 2.50
r = 0.98; SEE = 4.37 kg
Two-point method (Powerlift)
y = 1.13x - 6.02
r = 0.98; SEE = 4.30 kg
Mayhew equation
y = 1.02x + 0.76
r = 0.99; SEE = 2.92 kg
Wathan equation
y = 1.04x + 1.82
r = 0.99; SEE = 3.39 kg
Actual 1RM (kg)
Predicted 1RM (kg)
20
40
60
80
100
120

Figure 3



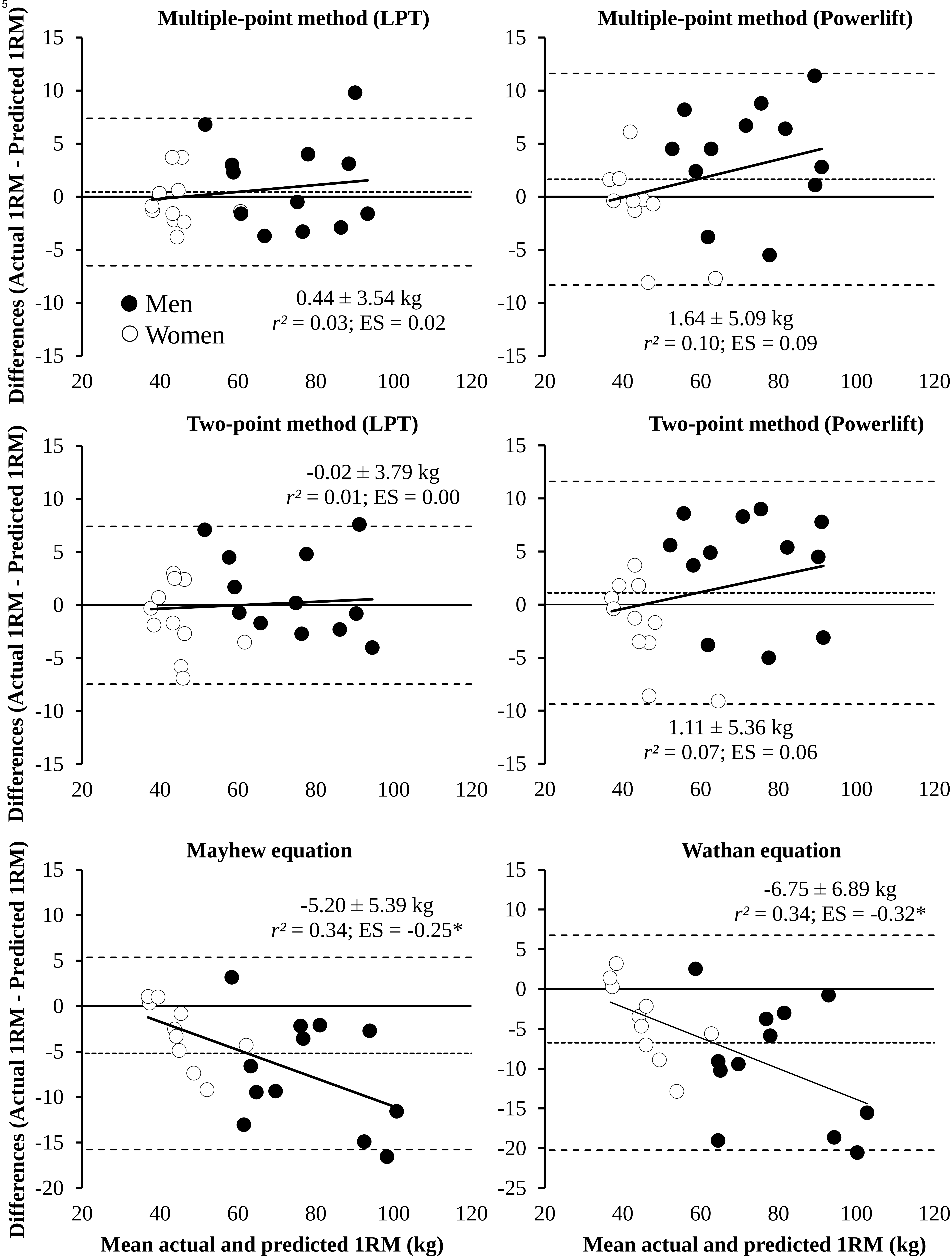
Multiple-point method (LPT)
y = 0.95x + 2.49
r = 0.98; SEE = 3.61 kg
Men
Women
Multiple-point method (Powerlift)
y = 0.88x + 5.35
r = 0.96; SEE = 5.12 kg
Two-point method (LPT)
y = 0.96x + 2.19
r = 0.99; SEE = 3.88 kg
Two-point method (Powerlift)
y = 0.89x + 5.56
r = 0.96; SEE = 5.44 kg
Mayhew equation
y = 1.14x - 3.14
r = 0.98; SEE = 4.12 kg
Wathan equation
y = 1.17x - 3.16
r = 0.96; SEE = 5.20 kg
Actual 1RM (kg)
Predicted 1RM (kg)

Figure 4



Multiple-point method (LPT)
-0.65 ± 4.61 kg
r² = 0.04; ES = -0.03
Multiple-point method (Powerlift)
-1.12 ± 5.00 kg
r² = 0.21; ES = -0.05
Two-point method (LPT)
-0.80 ± 4.29 kg
r² = 0.00; ES = -0.04
Two-point method (Powerlift)
-1.75 ± 5.42 kg
r² = 0.30; ES = -0.08
Mayhew equation
-2.14 ± 2.98 kg
r² = 0.05; ES =-0.10*
Wathan equation
-4.51 ± 3.61 kg
r² = 0.10; ES = -0.22*
Men
Women
Differences (Actual 1RM - Predicted 1RM)
Mean actual and predicted 1RM (kg)
15
10
5
0
-5
-10
-15
20
40
60
80
100
120

Figure 5


Multiple-point method (LPT)
Men
Women
0.44 ± 3.54 kg
r² = 0.03; ES = 0.02
Multiple-point method (Powerlift)
1.64 ± 5.09 kg
r² = 0.10; ES = 0.09
Two-point method (LPT)
-0.02 ± 3.79 kg
r² = 0.01; ES = 0.00
Two-point method (Powerlift)
1.11 ± 5.36 kg
r² = 0.07; ES = 0.06
Mayhew equation
-5.20 ± 5.39 kg
r² = 0.34; ES = -0.25*
Wathan equation
-6.75 ± 6.89 kg
r² = 0.34; ES = -0.32*
Differences (Actual 1RM - Predicted 1RM)
Mean actual and predicted 1RM (kg)