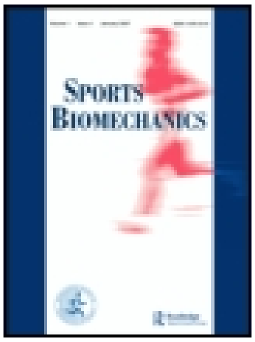

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The load-velocity profile differs more between men and women than between individuals with different strength levels

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ABSTRACT

This study aimed to determine the suitability of the load-velocity relationship to prescribe the relative load (%1RM) in women, as well as to compare the load-velocity profile between sexes and participants with different strength levels. The load-velocity relationship of 14 men (1RM: 1.17 ± 0.19) and 14 women (1RM: 0.66 ± 0.13) were evaluated in the bench press exercise. The main findings revealed that: (I) the load-velocity relationship was always strong and linear (R^2 range: 0.987–0.993), (II) a steeper load-velocity profile was observed in men compared to women (Effect size [ES]: 1.09), with men showing higher velocities for light loads (ES: – 0.81 and – 0.40 for the y-intercept and 30%1RM, respectively), but women reporting higher velocities for the heavy loads (ES: 1.14 and 1.50 at 90%1RM and 100%1RM, respectively); and (III) while the slope of the load-velocity profile was moderately steeper for weak men compared to their strong counterpart (ES: 1.02), small differences were observed between strong and weak women (ES: – 0.39). While these results support the use of the individual load-velocity relationship to prescribe the %1RM in the bench press exercise for women, they also highlight the large disparities in their load-velocity profile compared to men.

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KEYWORDS
Velocity-based resistance training; one-repetition maximum; relative load; movement velocity; bench press

Introduction

The use of load-velocity profiling is becoming popular in the strength and conditioning field, since several studies have shown that there exists a strong and negative relationship between the relative load (in terms of % of the 1-repetition maximum; 1RM) and the velocity at which the load is lifted (Banyard, Nosaka, & Haff, 2017; González-Badillo & Sánchez-Medina, 2010; Muñoz-Lopez, Marchante, Cano-Ruiz, Chicharro, & Balsalobre-Fernandez, 2017). Given the very high correlation between the load and movement

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velocity, the load-velocity profiling has been proposed as a time-efficient, non-invasive and accurate means of estimating the 1RM and, therefore, to prescribe the training loads during resistance training programs (González-Badillo, Marques, & Sánchez-Medina, 2011; Jovanonic & Flanagan, 2014; Mann, Ivey, & Sayers, 2015).

It has been observed that movement velocity can predict, with a high degree of accuracy ($R^2 > 0.97$ in most cases), the relative load in basic resistance training exercises such as the bench press, squat, or pull-up (Conceição, Fernandes, Lewis, Gonzaléz-Badillo, & Jimenéz-Reyes, 2016; González-Badillo & Sánchez-Medina, 2010; Muñoz-Lopez et al., 2017; Pérez-Castilla, García-Ramos, Padial, Morales-Artacho, & Feriche, 2017; Sánchez-Moreno, Rodríguez-Rosell, Pareja-Blanco, Mora-Custodio, & González-Badillo, 2017). Moreover, the load-velocity profile does not seem to differ between age-matched participants of different strength levels (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina, Pallarés, Pérez, Morán-Navarro, & González-Badillo, 2017). However, one of the main drawbacks of these studies is that, to the best of our knowledge, the load-velocity profile has been analysed almost exclusively in male participants. Therefore, there is a need to replicate this type of research with women to elucidate whether movement velocity is also a suitable tool to estimate %1RM in female participants, especially considering the well-known large differences in several strength-related capacities between men and women (Bishop, Cureton, & Collins, 1987; Miller, MacDougall, Tarnopolsky, & Sale, 1993). A recent study has shown that the velocity associated with each %1RM during the military press exercise is higher in men compared to women (Balsalobre-Fernández, García-Ramos, & Jiménez-Reyes, 2017). Similarly, young men reported higher velocity values for each %1RM when compared to middle-aged men (Fernandes, Lamb, & Twist, 2017). Although the underlying mechanisms of these differences are not fully understood, it is possible that some women and older individuals may possess a greater concentration of slow twitch fibres that may have impacted these results (Lexell, 1995; Staron et al., 2000).

To address the existing gaps in the literature, in the present study, we evaluated the load-velocity profile in the bench press exercise of both men and women participants. Specifically, the main objectives of the present study were (I) to determine the suitability of the load-velocity relationship to prescribe the relative load (%1RM) in women, as well as (II) to compare the load-velocity profile between men and women. Additionally, we also (III) explored the influence of strength level on the load-velocity profile separately for each sex. We hypothesised that (I) the load-velocity relationship would be strong and highly linear for all the groups analysed (García-Ramos & Jaric, 2017), (II) men would present a steeper load-velocity profile than women (i.e., the change in velocity for a given change in the %1RM would be higher for men) (Balsalobre-Fernández et al., 2017) and (III) no meaningful differences in the load-velocity profile would be obtained between strong and weak participants of the same sex (González-Badillo & Sánchez-Medina, 2010). The findings are expected to expand the applications of movement velocity for monitoring and prescribing the load during resistance training programs.

Methods

Participants

Although the power analysis conducted in previous studies revealed that sample sizes of only 3–9 participants were needed to detect the differences in mechanical variables (force, velocity and power) (Sreckovic et al., 2015), we conservatively recruited 14 men (age = 23.8 ± 2.5 years; body mass = 73.4 ± 8.9 kg; body height = 1.77 ± 0.07 m) and 14 women (age = 21.5 ± 1.4 years; body mass = 62.2 ± 8.7 kg; body height = 1.69 ± 0.06 m) to participate in this study. At the beginning of the study, men presented higher experience with the bench press exercise than women (6.2 ± 2.0 and 1.2 ± 1.5 years, respectively). Participants did not report any physical limitations, health problems or musculoskeletal injuries that could compromise testing. They were also instructed to avoid any strenuous exercise two days before the testing session. All participants 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 University of Granada Institutional Review Board.

Experimental design

This study was designed to examine whether there exist differences in the load-velocity profile between men and women. Prior to the testing session designed to assess the load-velocity profile, participants were involved in a 4-week training period (twice a week, with 48–72 h of rest between sessions) with the objectives of increasing strength levels and ensuring proper technique. In each training session participants performed 5 sets of the bench press exercise in a Smith machine as well as some complementary exercises such as the seated military press, lat pulldown or leg press. The intensity in the bench press exercise ranged from ≈ 60%1RM to ≈ 90%1RM. A linear velocity transducer was used to measure barbell velocity during all training sessions and the participants were told to stop when the mean velocity (MV) of the barbell dropped below 0.30 m/s in men and 0.35 m/s in women (approximately 2–3 repetitions in reserve) (García-Ramos et al., 2017). Different stopping velocities were used to leave a similar number of repetitions in reserve since the velocity of the 1RM is higher for women than men. The testing session consisted of an incremental loading protocol in the bench press exercise up to the 1RM. All participants were evaluated in the afternoon (between 16:00 and 20:00 h) and under similar environmental conditions (~22ºC and ~60% humidity).

Testing procedures

The testing session began with a 10-min standardised warm-up, which included jogging, dynamic stretching, arm and shoulder mobilisation and one set of five repetitions performed as fast as possible with an external load of 17 kg (mass of the unloaded Smith machine barbell) in the bench press exercise. After warming up, participants rested for 3 min before undertaking an incremental load test. The initial external load for this test was set at 17 kg for both sexes. The load was progressively increased by 10 kg increments for men and 5 kg increments for women until the attainment of MV was lower than 0.50 m/s. From that moment, the load was progressively increased in steps of 0.5 to 5 kg for men and 0.5 kg to 2.5 kg for women until the actual 1RM was directly determined with the completion of a single maximal lift. The magnitude of the load increment was decided by a skilled investigator after reaching a consensus with the participant. For the lighter loads (MV > 1.0 m/s), three attempts were executed at each load, two for the medium (0.65 m/s ≤ MV ≤ 1.0 m/s) and only one for the heavier loads (MV < 0.65 m/s). The rest period between the repetitions performed with the same load was 10 s. The rest period between different loading conditions was set to 3 min for lighter and medium loads, while 5 min were implemented between the heavier loads. Two trained spotters were present at both sides of the barbell on the Smith machine to ensure safety and encourage the participants to lift the barbell at the maximum possible velocity. In addition, participants received velocity performance feedback immediately after completing each repetition to further encourage them to give maximal effort.

Participants performed the bench press using the standard five-point body contact position technique (head, upper back and buttocks firmly on the bench with both feet flat on the floor) and with a self-selected grip width that was kept constant on every lift. Participants initiated the task holding the barbell with their elbows fully extended. From this position, they were instructed to perform the downward phase until contacting with their chest at the lower portion of the sternum, and immediately after contact they performed the upward phase of the lifting as fast as possible. The upward phase ended when the participants' elbows reached full extension.

Measurement equipment and data analysis

Height (Seca 202, Seca Ltd., Hamburg, Germany) and body mass (Tanita BC 418 segmental, Tokyo, Japan) were assessed at the beginning of the testing session prior to the initiation of the warm-up. A Smith machine (Technogym, Barcelona, Spain) coupled with a linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) which sampled the velocity of the barbell at a frequency of 1,000 Hz was used during the incremental loading test. The MV (i.e., average velocity from the onset of positive velocity until the barbell reaches maximum height) was used to model the load-velocity profiles. The MV was selected as the key measurement based upon previous research which has recommended using the MV over mean propulsive velocity and peak velocity when determining the load-velocity profile (García-Ramos, Pestaña-Melero, Pérez-Castilla, Rojas, & Haff, 2017).

Only the repetition with the highest MV value of each loading condition was used for subsequent analysis. The loads that represented less than a 30%1RM were also excluded from the analysis to ensure that the load-velocity profiles were modelled with a similar range of relative loads for men and women. The MV attained at each %1RM (in 10% increments from 30%1RM to 100%1RM) were obtained from the individual load-velocity relationships after applying first-order polynomials to the data. Note that the linear regression model has been reported to provide a more reliable load-velocity profile when compared to the use of a second-order polynomial when applied to the bench press exercise (Pestaña-Melero, Haff, Rojas, Pérez-Castilla, & García-Ramos, 2017). To assess the effect of strength level on the load-velocity profile, the groups of men and women were divided in two subgroups of strong and weak participants according to their 1RM relative to body mass: (I) strong men, (II) weak men, (III) strong women and (IV) weak women. Therefore, the strong groups consisted of the 7 men and 7 women with the highest relative 1RM bench press strength, while the 7 men and 7 women with the lowest relative 1RM bench press were included in the weak groups.

Statistical analyses

Data are presented as means and standard deviations, while the Pearson's multivariate coefficient of determination (R^2) is presented through their median values and ranges. The magnitude of the differences in the 1RM strength (absolute and relative to body mass values) and in the velocity of the 1RM was compared between sexes (men *vs.* women) and strength levels (strong *vs.* weak) through the Cohen's effect size (ES). The criteria for interpreting the magnitude of the ES were: trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0) and extremely large (>2.0) (Hopkins, Marshall, Batterham, & Hanin, 2009). The relationship between relative load (%1RM) and MV was established by means of linear regression models (Banyard et al., 2017; Conceição et al., 2016). The goodness of fit of the linear regressions was assessed by r^2. The Fisher's Z-transformed Pearson's correlation coefficients (r) of the individual load-velocity profiles were compared through a two-way ANOVA with sex (men *vs.* women) and strength level (strong *vs.* weak) as between-participants factors. The differences in the load-velocity profile (i.e., slope of the load-velocity profile, y-intercept and MV from 30%1RM to 100%1RM in 10% increments) were also assessed with the ES and its 90% confidence interval. The ANOVA was performed using SPSS software version 22.0 (SPSS Inc., Chicago, IL, USA) and statistical significance was set at an alpha level of 0.05, while all other statistical analyses were performed with a custom Excel spreadsheet.

Results

The differences in the 1RM value between men and women were very large (absolute 1RM ES = 4.01; relative 1RM ES = 3.23) (Table 1). As expected, the 1RM value was higher for strong than weak participants for both men (absolute 1RM ES = 1.62; relative 1RM ES = 2.84) and women (absolute 1RM ES = 0.85; relative 1RM ES = 2.60). On the other hand, the velocity of the 1RM was higher for women than men (ES = 0.90). It should be also noted that while trivial differences in the velocity of the 1RM were observed between strong and weak men (ES = 0.18), moderate higher values were observed for weak women compared to their strong counterparts (ES = 0.78).

The analysis of the whole data-set revealed a strong linear relationship between MV and relative load (%1RM) either for men ($R^2 = 0.95$) and women ($R^2 = 0.94$) (Figure 1). The individual load-velocity relationships were also very strong for both sexes ($R^2 = 0.994$ [0.981, 0.999] for men and $R^2 = 0.992$ [0.963, 0.999] for women). The ANOVA applied on the Fisher's Z-transformed r coefficients did not reveal significant main effects for sex ($F = 0.01, p = 0.935, \eta_p^2 = 0.00$), strength levels ($F = 0.64$, $p = 0.433$, $\eta_p^2 = 0.03$) or their interaction ($F = 0.80$, $p = 0.381$, $\eta_p^2 = 0.032$) (Figure 2).

Table 1. One-repetition maximum (1RM) value and its associated velocity observed in the different groups studied.

	Men			Women		
Variable	All ($n = 14$)	Strong ($n = 7$)	Weak ($n = 7$)	All ($n = 14$)	Strong ($n = 7$)	Weak ($n = 7$)
Absolute 1RM (kg)	85.2 ± 14.5	94.4 ± 12.0	76.0 ± 10.7#	39.9 ± 8.1*	43.1 ± 8.8	36.7 ± 6.2#
Relative 1RM	1.17 ± 0.19	1.32 ± 0.13	1.02 ± 0.08#	0.66 ± 0.13*	0.75 ± 0.11	0.56 ± 0.04#
Velocity 1RM (m/s)	0.167 ± 0.037	0.171 ± 0.039	0.164 ± 0.037	0.208 ± 0.053*	0.188 ± 0.052	0.228 ± 0.050#

Notes: Men and women were divided in 'strong' and 'weak' groups according to their relative 1RM (i.e., 1RM normalised per kg of body mass).
*Significantly different than men; #significantly different than their strong counterparts.

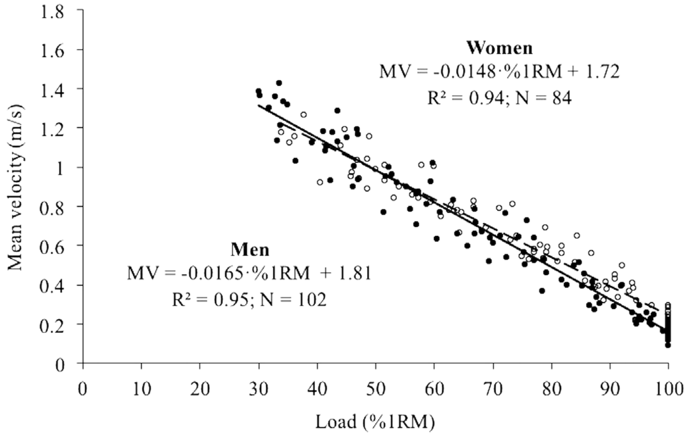

Figure 1. Relationship between relative load (%1RM) and mean velocity (MV) for men (filled dots and solid line) and women (open dots and dashed line). R2, Pearson's multivariate coefficient of determination; *N* = number of trials included in the regression analysis.

Steeper load-velocity profiles were observed in men compared to women (ES = 1.09) (Figure 3). As a consequence, while men achieved higher MV for light loads (e.g., the ES was − 0.81 and − 0.40 for the y-intercept and 30%1RM, respectively), women reported higher MV for the heavy loads. Finally, it should be noted that while the slope of the load-velocity profile was moderately steeper for weak men compared to their strong counterpart (ES = 1.02), small differences in the slope of the load-velocity profile was observed between strong and weak women (ES = − 0.39) (Figure 4).

Discussion and implications

The present study was designed to elucidate whether the strong association between relative load (%1RM) and movement velocity commonly reported for men can be extrapolated to women, as well as to determine the possible differences in the load-velocity profile that may exist between both sexes. Our main findings revealed (I) a very strong and linear relationship between MV and %1RM regardless of the sex and strength level of the participants, (II) large differences in the velocity associated to each %1RM between men and women due

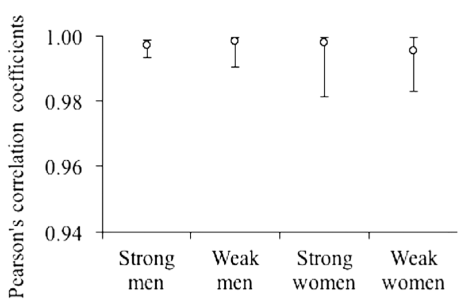

Figure 2. Pearson's correlation coefficients (median value with its range) obtained from the individual load-velocity relationships.

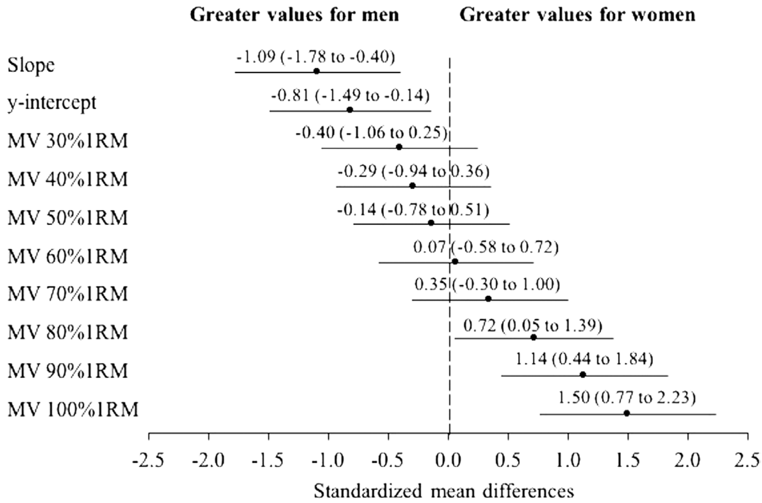

Figure 3. Standardised mean differences (90% confidence intervals) in the load-velocity profile between men and women. Slope, absolute value of the slope of the load-velocity linear regression; y-intercept, y-intercept of the load-velocity linear regression (i.e., MV at 0%1RM); MV, mean velocity; 1RM, one-repetition maximum.

to a steeper load-velocity profile in men and (III) a steeper load-velocity profile for weak men than strong men, but small differences generally observed between weak and strong women. These results collectively support the use of MV to prescribe the %1RM regardless of the sex and strength level of the individuals. However, our results also highlight that the load-velocity profile largely differs between men and women, while the maximal strength level (i.e., 1RM relative to body mass) does not seem to be responsible for the between-sex differences in the load-velocity profile.

Our first hypothesis was confirmed since women showed an exceptionally strong and linear relationship between MV and the relative load (%1RM). It should be also highlighted that the accuracy of the load-velocity relationship was high for both men and women as well as for weak and strong participants. The goodness of fit of the individual load-velocity relationships obtained in the present study ($R^2 = 0.99$) was similar to previously reported data for the bench press exercise ($R^2 \approx 0.99$) (Sánchez-Medina, González-Badillo, Pérez, & Pallarés, 2014), as well as for other basic resistance training exercises such as the squat ($R^2 \approx 0.98$) (Pérez-Castilla et al., 2017), vertical jumps ($R^2 \approx 0.98$) (Pérez-Castilla et al., 2017), bench pull ($R^2 \approx 0.99$) (Sánchez-Medina et al., 2014) and pull-up ($R^2 \approx 0.98$) (Muñoz-Lopez et al., 2017). The high linearity of the load-velocity relationship supports the use of the linear regression model instead of more complex calculation methods (e.g., polynomial model) (Bobbert, 2012). In this regard, an almost perfect concurrent validity (trivial effect sizes [from 0.02 to 0.17] and very high correlations [r ranged from 0.96 to 0.98]) of the bench press 1RM predicted by the two-point method (i.e., load-velocity relationship modelled through only 2 data points) has been reported with respect to the directly measured 1RM (García-Ramos et al., 2017). Therefore, the results of the present study add to the evidence that movement velocity can be used to accurately estimate the relative load (%1RM) through a linear regression model regardless of the sex and strength levels of the participants.

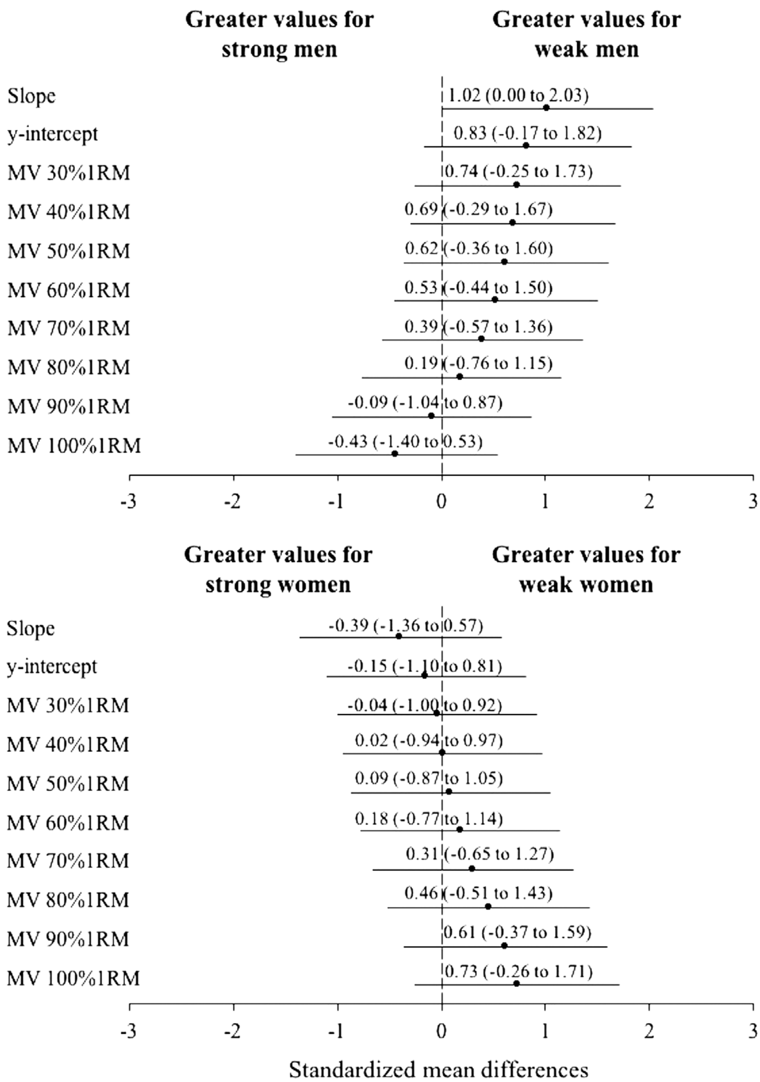

Figure 4. Standardised mean differences (90% confidence intervals) in the load-velocity profile between strong and weak men (upper panel) and women (lower panel). Slope, absolute value of the slope of the load-velocity linear regression; y-intercept, y-intercept of the load-velocity linear regression (i.e., MV at 0%1RM); MV, mean velocity; 1RM, one-repetition maximum.

Supporting our second hypothesis, large differences in the load-velocity profile were observed between men and women, with men possessing a steeper load-velocity profile than women. As a consequence, while the MV associated with the light loads (≈ 30%1RM) was higher for men, women presented higher MV values for heavy loads (≈ 100%1RM). These results speak against using generalised group equations that were proposed with the objective of predicting the %1RM from the velocity recorded against a single loading condition (Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010; Pallarés, Sánchez-Medina, Pérez, De La Cruz-Sánchez, & Mora-Rodriguez, 2014; Pérez-Castilla et al., 2017). It should be noted that the results of the present study would encourage the use of different equations for men and women. However, since meaningful differences in the load-velocity profile have also been reported for men (Helms et al., 2017; Pestaña-Melero et al., 2017), the individual modelling of the load-velocity profile is preferable for a more accurate prescription of the %1RM. Note that an individual prediction of the 1RM could be obtained from the velocity data collected under only 2 different loading conditions (i.e., two-point method) (García-Ramos et al., 2017).

To the best of our knowledge, the present study has explored for the first time the differences in the load-velocity profile between men and women during the bench press exercise. Men reported a steeper slope for the load-velocity relationship (i.e., the change in MV for a given change in the %1RM was higher for men than women). It should be also noted that the velocity of the 1RM trial was higher in women (≈ 0.21 m/s) as compared to men (≈ 0.17 m/s). The higher experience of men with the bench press exercise could be responsible of these results. In this regard, it has been postulated that the differences in the velocity recorded during the 1RM trial could be responsible of the differences in the velocity associated to each %1RM (González-Badillo & Sánchez-Medina, 2010). Namely, participants with a higher velocity during the 1RM trial are also expected to have higher velocities for other relative loads (i.e., %1RM) (González-Badillo & Sánchez-Medina, 2010). However, while women reported a higher MV during the 1RM trial, men presented higher MV values for the light relative loads (e.g., 30%1RM). Therefore, it seems that other factors beyond an erroneous determination of the 1RM, typically associated with a high velocity during the 1RM trial, should be responsible of the differences in the load-velocity profile between men and women.

To take into account the potential confounding factor of the different strength levels between men and women, we also evaluated the differences in the load-velocity profile between strong and weak participants separately for each sex. Note that if the observed differences between men and women (i.e., steeper load-velocity profile for men that are stronger) were caused by their different strength levels, we could expect that the stronger participants of each sex also present a steeper load-velocity profile than their weaker counterparts. However, weaker men presented a steeper load-velocity profile than their stronger counterparts (ES = 1.02), while small differences in slope of the load-velocity profile was observed between weak and strong women (ES = – 0.39). These data suggest that the differences between men and women are not directly caused by their different strength levels. Therefore, although the underlying mechanisms require further investigation, it could be possible that the higher predominance of slow muscle fibres in women compared to men could be one of the factors responsible for their lower velocity associated with light relative loads (Lexell, 1995; Staron et al., 2000).

Conclusion

Movement velocity can be used to accurately prescribe the relative load (%1RM) regardless of the sex and strength levels of the participants. The prominent differences in the load-velocity profile between men and women highlight that the error of the generalised group equations obtained with male participants may be increased when they are applied to female participants. The results of the present study provide additional support for using the individual load-velocity relationship instead of generalised group equations for a more accurate prescription of the %1RM. Considering that the load-velocity relationship can be accurately determined by registering the velocity of just two different loads, which can be measured with affordable smartphone or wearable technologies, individual load-velocity profiles can be easily determined nowadays.

Disclosure statement

No potential conflict of interest was reported by the authors.

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