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RESEARCH

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Gauging proximity to failure in the bench press: generalized velocity-based vs. %1RM-repetitions-to-failure approaches

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Abstract

Background This study compared the accuracy of three generalized approaches for estimating proximity to failure during the Smith machine bench press: (i) the relationship between relative load (%1RM) and maximum repetitions performed to failure (%1RM-RTF), (ii) the relationship between maximum repetitions to failure and fastest set velocity (RTF-velocity), and (iii) the relationship between repetitions left in reserve (RIR) and lifting velocity (RIR-velocity).

Methods Nineteen physically active men (22.9 ± 2.7 years old) with at least two years of resistance training experience participated. Their 1-repetition maximum (1RM = 86.8 ± 16.7 kg) was determined during the first session. In the second session, participants performed single sets to failure at 60% and 80% 1RM, with proximity to failure (2RIR and 4RIR) estimated using each approach.

Results The RIR-velocity relationship was the only approach that did not significantly deviate from the intended RIR (errors = -0.4 to 0.6 repetitions). In contrast, both the %1RM-RTF and RTF-velocity relationships overestimated the intended RIR at 60%1RM for both 2RIR (2.9 and 5.8 repetitions, respectively) and 4RIR (2.8 and 5.7 repetitions, respectively), while no significant differences were observed at 80%1RM (errors = -0.6 to 0.9 repetitions). The RIR-velocity relationship generally demonstrated the lowest absolute errors compared to the actual RIR (1.3 ± 0.7 repetitions), with greater differences compared to the other two approaches at lighter loads and closer proximities to failure.

Conclusions In the absence of individual relationships, the general RIR-velocity relationship should be used by coaches to control the proximity to failure of their athletes during the bench press exercise.

Keywords Level of effort, Monitoring, Resistance training, Velocity-based training

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Introduction

Resistance training (RT) is widely recognized as a fundamental component of physical conditioning, playing a crucial role in promoting muscular development, enhancing athletic performance, and improving overall health [1–3]. Among the key variables that influence its effectiveness, training volume stands out as one of the most critical factors [4, 5]. Closely tied to this is the concept of *level of effort*, defined as the number of repetitions performed in a set relative to the maximum possible, which has received substantial research attention due to its significant impact on both post-training recovery and long-term performance adaptations [6–8]. As a result, there is growing consensus that training to failure should be minimized in most contexts, as less fatiguing methods can achieve equal or superior outcomes [6, 9]. Consequently, there is a need for precise and reliable strategies to prescribe repetition volume that align with the desired level of effort (i.e., proximity to failure) while avoiding reliance on failure-based approaches.

Traditional methods for prescribing repetition volume often rely on predictive tables, which estimate the number of repetitions an individual can perform to failure (RTF) based on the specific exercise and relative load. For example, Nuzzo et al. [10] reported that during the bench press, individuals (regardless of sex, age, or training status) can perform an average of 19 repetitions at 60% of their one-repetition maximum (1RM) and 9 repetitions at 80% of their 1RM. Using this approach, a coach aiming to maintain a moderate level of effort—such as leaving 4 repetitions in reserve—might prescribe 15 and 5 repetitions at 60% and 80% of 1RM, respectively. However, the %1RM-RTF method has some notable limitations. It requires precise knowledge of the exact %1RM being lifted, which is often impractical, requiring frequent reassessments of the 1RM because fluctuations in muscle strength can occur as a result of training- or non-training-related stressors [11]. It also fails to account for significant inter-individual variability in the number of repetitions achievable at a given %1RM [12–14]. In addition, factors such as lifting tempo and range of motion can also influence the maximum number of repetitions an individual can perform at a given load [15, 16]. This variability highlights the risk of fixed prescriptions unintentionally pushing some individuals to failure while allowing others to complete the prescribed volume with ease, potentially resulting in inconsistent training adaptations.

To address these challenges, velocity-based training (VBT) has emerged as a modern approach to RT prescription, providing tools to enhance and complement the effectiveness of traditional methods [11]. A key proposed advantage of VBT is its potential to control and regulate effort levels during RT sessions while accounting for variations in daily physical readiness to train and individual performance capabilities [11]. Notably, a higher velocity at a given absolute load indicates an improved strength capacity, while a greater decline in velocity across repetitions is associated with increased fatigue and closer proximity to failure [17]. The two primary velocity-based strategies for prescribing repetition volume to leave a specific number of repetitions in reserve are (i) the relationship between the maximum number of repetitions performed to failure and the fastest set velocity (RTF-velocity relationship) [18, 19], and (ii) the relationship between repetitions left in reserve and lifting velocity (RIR-velocity relationship) [8, 20]. Similar to the traditional %1RM-RTF relationship, these velocity-based strategies can be applied using either generalized or individualized relationships. While individualized relationships provide greater accuracy in estimating proximity to failure, they require individuals to perform sets to failure for their assessment, which presents practical challenges. Note that training to failure intensifies immediate mechanical, metabolic, and perceptual fatigue and prolong recovery periods following RT sessions [21–23], whereas it fails to maximize neuromuscular adaptations and strength gains [6, 24, 25].

For coaches aiming to avoid prescribing sets to failure, it is essential to identify which of the general approaches discussed above provides the most accurate estimation of proximity to failure, specifically by minimizing errors in predicting repetitions in reserve (RIR). The primary objective of this study was to compare the accuracy of generalized relationships from three approaches—(i) %1RM-RTF, (ii) RTF-velocity, and (iii) RIR-velocity—in gauging proximity to failure during the Smith machine bench press. We hypothesized that velocity-based strategies would enhance the precision of effort prescription compared to traditional %1RM-RTF tables, particularly by accounting for variations in physical readiness to train and individual performance capacities. The expected findings are important for determining whether general (i.e., non-individualized) velocity thresholds can provide a more accurate alternative to traditional %1RM-RTF predictive models, ultimately informing more effective RT practices.

Methods

Participants

Nineteen healthy young men participated in this study (mean ± standard deviation: age 22.9 ± 2.7 years, body mass 73.0 ± 8.6 kg, height 1.77 ± 0.07 m). All participants were physically active, engaged in RT 2–5 times per week, and had at least two years of RT experience. Their 1RM in the bench press was 86.8 ± 16.7 kg (1.19 ± 0.18 kg per kg of body mass). Participants were instructed to abstain from strenuous physical activity for 48 h prior to each testing session. Each participant had previously taken part in studies conducted by our research team, demonstrating proficiency in executing the bench press with proper technique at maximal intended velocity. Before starting the study, all participants received detailed information about the procedures and provided written informed consent. The study complied with the principles outlined in the Declaration of Helsinki and was approved by the institutional ethics committee.

Design

This study utilised a repeated-measures design to compare the accuracy of generalized relationships from three approaches for estimating proximity to failure during the bench press: (i) %1RM-RTF, (ii) RTF-velocity, and (iii) RIR-velocity. Participants attended two testing sessions within the same week, separated by 48 to 96 h of rest. During the first session, each participant's 1RM in the Smith machine bench press was determined. In the second session, participants performed single sets of repetitions to failure at maximal intended velocity using two relative loads (80% and 60% of 1RM). The accuracy of each prescription approach (%1RM-RTF, RTF-velocity, and RIR-velocity) in estimating proximities to failure at two (2RIR) and four (4RIR) repetitions was analysed for both loads (60%1RM and 80%1RM). Both sessions were conducted at the same time of day for each participant (± 1 h).

Procedures

The general warm-up for both testing sessions consisted of 5 min of jogging, followed by self-selected dynamic stretching and upper-body joint mobilization exercises. In the first session, the 1RM in the Smith machine bench press was determined using a standardized incremental loading protocol, as described by García-Ramos et al. [26]. The test began with an initial external load of 17 kg, which was progressively increased from 1 to 10 kg until the 1RM was directly measured through the successful completion of a single maximal lift. This protocol has demonstrated high reliability in similar populations, with a coefficient of variation of 1.86% and an intraclass correlation coefficient of 0.98 [26], which supports the decision not to include a second testing session to confirm 1RM performance.

During the second session, participants performed single sets of repetitions to failure at 80% and 60% of the 1RM determined in the first session. The loads were applied in descending order, as reaching failure with lighter loads is more fatiguing. To minimize fatigue effects, a 10-minute rest period separated the two sets. Before starting the sets to failure, participants completed a specific warm-up consisting of three sets of 10, 5, and 2 repetitions at relative loads of 40%1RM, 60%1RM, and 80%1RM, respectively. Rest intervals of 2 min were provided between warm-up sets, with a 4-minute rest period between the final warm-up set and the first set to failure.

Participants performed the bench press using a standardized execution technique across all testing sessions. Each repetition began with the barbell held at arm's length, elbows fully extended, and a self-selected grip width. From this starting position, participants were instructed to perform both the downward (eccentric) and upward (concentric) phases of the movement as fast as possible. The barbell was lowered until it made contact with the chest (visually inspected by an experienced researcher), and the concentric phase ended when the elbows returned to full extension. Participants were instructed to maintain the same execution technique throughout all repetitions in both testing sessions. Participants received real-time velocity feedback following each repetition to ensure maximal intent [27]. Additionally, an experienced researcher closely monitored and verbally encouraged participants to lift the barbell at maximal intended velocity and to complete the maximum possible number of repetitions, ensuring that no more than a 1-second pause occurred between consecutive repetitions.

Measurement equipment and data analysis

A Smith machine (Technogym, Barcelona, Spain) was utilized during all testing sessions, equipped with a validated linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) that recorded movement velocity at a sampling frequency of 1000 Hz [21]. The variable analysed in this study to apply the velocity-based strategies for prescribing repetition volume was the mean velocity (MV) of the barbell. This was defined as the average velocity during the concentric phase, measured from the initiation of the upward movement to the point where the barbell reached its maximum height. The basic characteristics of the three approaches used in this study to gauge proximity to failure are described below.

1. ***%1RM-RTF relationship***. Nuzzo et al. [10] reported that, on average, individuals can perform a maximum of 19 repetitions at 60% of their 1RM and 9 repetitions at 80% of their 1RM during the bench press. Using this approach, when participants completed more repetitions than those stipulated by Nuzzo et al. [10], the RIR was overestimated. For example, if a participant completed 21 repetitions at 60% of their 1RM, the 2RIR and 4RIR would be overestimated by two repetitions. Conversely, when participants completed fewer repetitions than those stipulated by Nuzzo et al. [10], the RIR was underestimated. For instance, if a participant completed only 17 repetitions at 60% of their 1RM,

the 2RIR and 4RIR would be underestimated by two repetitions. In two cases, participants reached failure three repetitions before achieving the number of repetitions stipulated by Nuzzo et al. [10]. Specifically, one participant performed only 16 repetitions at 60% of their 1RM, and another performed only 6 repetitions at 80% of their 1RM. In these instances, we assumed an underestimation of two repetitions for 2RIR and three repetitions for 4RIR, as the underestimation cannot exceed the intended RIR.

2. ***RTF-velocity relationship***. According to García-Ramos et al. [18], the maximum number of repetitions to failure (RTF) during the Smith machine bench press can be predicted using the equation: RTF = 37.01·MV – 7.95 ($r^2 = 0.774$, standard error of the estimate = 3.57 repetitions), where MV represents the fastest mean velocity. The fastest MV recorded during the first two repetitions was used to predict the RTF. For example, a starting velocity of 0.64 m·s^{-1} would yield a predicted RTF of 16 repetitions. However, discrepancies between the predicted and actual RTF were observed. Three participants reached failure three repetitions earlier than predicted, and one participant was four repetitions short of the prediction. To compute the magnitude of the errors (underestimation or overestimation), the same criteria used for the %1RM-RTF relationship were applied.
3. ***RIR-velocity relationship***. According to Morán-Navarro et al. [8], the MV corresponding to two and four RIR are 0.27 m·s^{-1} and 0.36 m·s^{-1}, respectively. In the present study, the set was considered terminated once these MV thresholds were exceeded for the first time. At this point, the number of repetitions performed afterward, before reaching failure, was recorded. The errors were calculated as the difference between the actual RIR (i.e., the exact number of repetitions completed after exceeding the MV threshold) and the intended RIR. Specifically, an intended RIR of four was assigned for exceeding 0.36 m·s^{-1}, and an intended RIR of two was assigned for exceeding 0.27 m·s^{-1}.

Statistical analyses

Data are presented as mean ± standard deviation. Given that RIR is not a continuous variable, alternative non-parametric statistical procedures were applied in the present study. Wilcoxon signed-rank tests were conducted to determine whether significant differences existed between the intended RIR (2RIR or 4RIR) and the actual RIR obtained using the different repetition volume prescription approaches (%1RM-RTF, RTF-velocity, and RIR-velocity). The Friedman test, followed by LSD post hoc comparisons, was used to compare the absolute differences between actual and intended RIR across the three prescription approaches (%1RM-RTF, RTF-velocity, and RIR-velocity) for each intended RIR (2RIR and 4RIR) and load condition (60%1RM and 80%1RM). All statistical analyses were conducted using SPSS software (version 25.0, SPSS Inc., Chicago, IL, USA), with the significance level set at $p \leq 0.05$.

Results

The actual RIR obtained using the various approaches for prescribing repetition volume (%1RM-RTF, RTF-velocity, and RIR-velocity) are shown in Fig. 1. Among the methods, the RIR-velocity relationship was the only approach that did not significantly deviate from the intended RIR for any load: 60%1RM at 2RIR (1.6 ± 1.2 repetitions), 60%1RM at 4RIR (4.1 ± 2.3 repetitions), 80%1RM at 2RIR (1.8 ± 1.3 repetitions), and 80%1RM at 4RIR (4.6 ± 2.0 repetitions). In contrast, both the %1RM-RTF and RTF-velocity relationships overestimated the intended RIR at 60%1RM for both 2RIR (4.9 ± 3.5 and 7.8 ± 5.1 repetitions, respectively) and 4RIR (6.8 ± 3.5 and 9.7 ± 5.2 repetitions, respectively). However, no significant differences were observed for the 1RM-RTF and RTF-velocity relationships at 80%1RM for 2RIR (1.4 ± 1.2 and 2.9 ± 2.5 repetitions, respectively) or 4RIR (3.4 ± 1.3 and 4.9 ± 2.5 repetitions, respectively).

The absolute differences between the actual and intended RIR for three prescription approaches (%1RM-RTF, RTF-velocity, and RIR-velocity) are depicted in Fig. 2. The Friedman test at 60%1RM revealed significant differences for both 2RIR ($p < 0.001$) and 4RIR ($p = 0.001$). In both cases, the RIR-velocity relationship exhibited lower absolute errors than the %1RM-RTF and RTF-velocity relationships, while the %1RM-RTF relationship also showed lower errors than the RTF-velocity relationship. The Friedman test at 80%1RM also revealed significant differences for both 2RIR ($p = 0.009$) and 4RIR ($p = 0.045$). In both cases, the RIR-velocity relationship exhibited lower absolute errors than the RTF-velocity relationship, while no significant differences were found between the %1RM-RTF relationship and either the RTF-velocity or RIR-velocity relationships.

Discussion

This study was designed to evaluate the accuracy of various general approaches for estimating proximity to failure (%1RM-RTF, RTF-velocity, and RIR-velocity) during the Smith machine bench press. Among these methods, the RIR-velocity relationship emerged as the most accurate, consistently aligning with the intended RIR without systematic differences. In contrast, the %1RM-RTF and RTF-velocity approaches tended to overestimate the intended RIR at 60%1RM, showing no significant

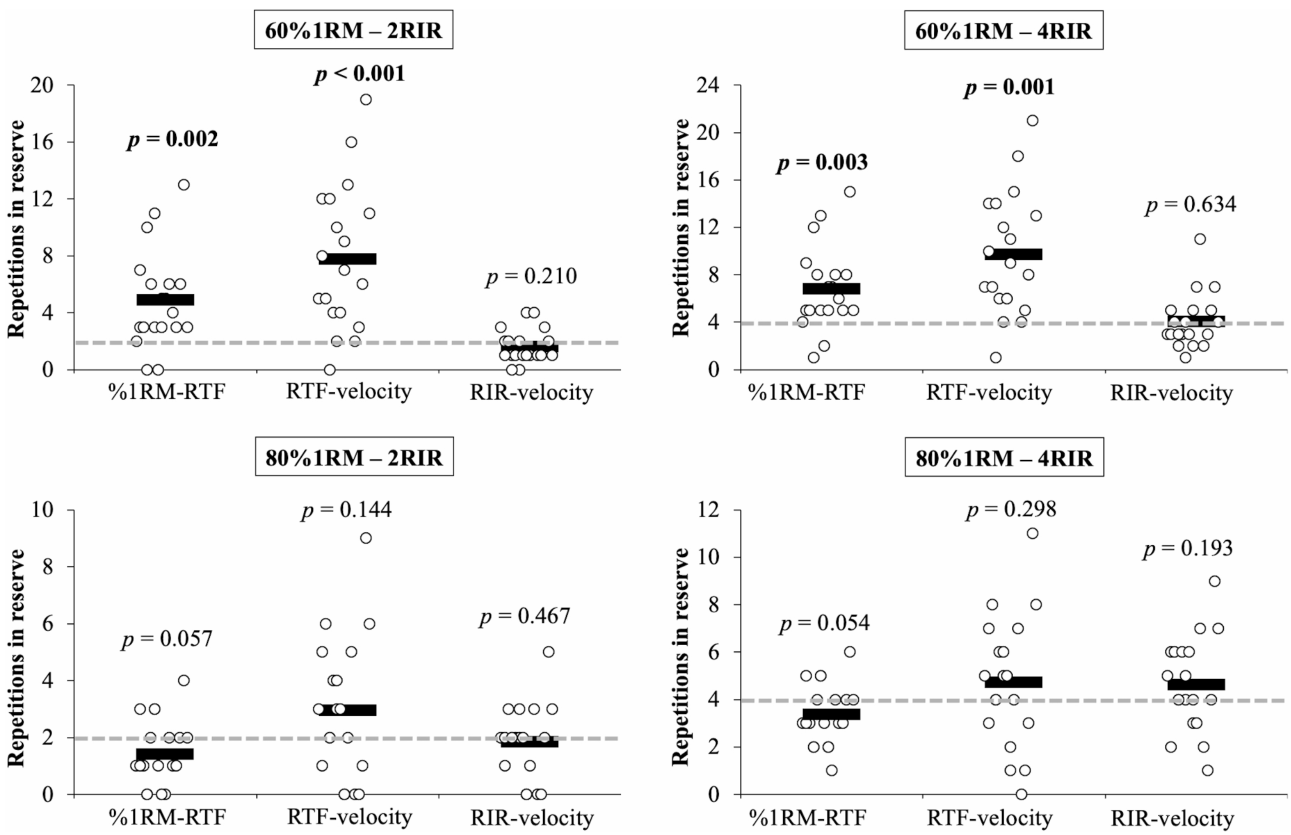

Fig. 1 Actual repetitions in reserve (RIR) obtained using three different approaches for prescribing repetition volume: %1RM-RTF, RTF-velocity, and RIR-velocity. Data are presented for intended RIR targets of 2 and 4 repetitions at two relative loads (60%1RM and 80%1RM). Solid horizontal lines represent the mean RIR for each approach, and individual data points are shown. *p*, *p*-value derived from Wilcoxon signed-rank tests comparing the intended and actual RIR

deviations at 80%1RM. Furthermore, the RIR-velocity relationship demonstrated the lowest absolute errors overall, with these differences being more pronounced at lighter loads (60%1RM vs. 80%1RM) and closer proximities to failure (2RIR vs. 4RIR). Taken together, these findings suggest that, in the absence of individual relationships, the general RIR-velocity relationship provides a more accurate method for estimating proximity to failure during the bench press exercise compared to general %1RM-RTF and RTF-velocity relationships.

Nuzzo et al. [10] recently updated the predictive tables commonly used to estimate the maximum number of repetitions individuals can perform to failure at various relative loads (%1RM). The bench press was the most represented exercise in this analysis, accounting for 42% of the studies included in the meta-analysis. Specifically for the bench press, Nuzzo et al. [10] found minimal influence of factors such as sex, age, or training status on the %1RM-RTF relationship, recommending the use of the same generalized relationship for all individuals performing this exercise. However, our findings revealed some discrepancies: participants in this study completed more repetitions at 60%1RM (21.8 ± 3.5) and fewer repetitions at 80%1RM (8.4 ± 1.3) compared to the 19 and 9 repetitions predicted by Nuzzo's tables for 60%1RM and 80%1RM, respectively. These discrepancies led to a significant overestimation of approximately 2.8 repetitions at 60%1RM and a non-significant underestimation of approximately 0.6 repetitions at 80%1RM. Interestingly, the predictive tables exhibited similar errors for both 2RIR and 4RIR; however, the errors increased as the load decreased, making the approach more accurate at heavier loads closer to 1RM. Importantly, two participants in our study reached failure three repetitions before achieving the predicted 2RIR value. This variability highlights the inherent risks of relying on fixed %1RM-RTF prescriptions, which may unintentionally push some individuals to failure while allowing others to complete the prescribed volume with ease. These limitations are particularly relevant in team sports environments (e.g., soccer, rugby, hockey), where athletes engage in concurrent training, combining RT with high-intensity activities such as sprinting and sport-specific drills, often with minimal recovery between training blocks. This context can lead to significant fluctuations in muscle strength (i.e., 1RM), further reducing the accuracy

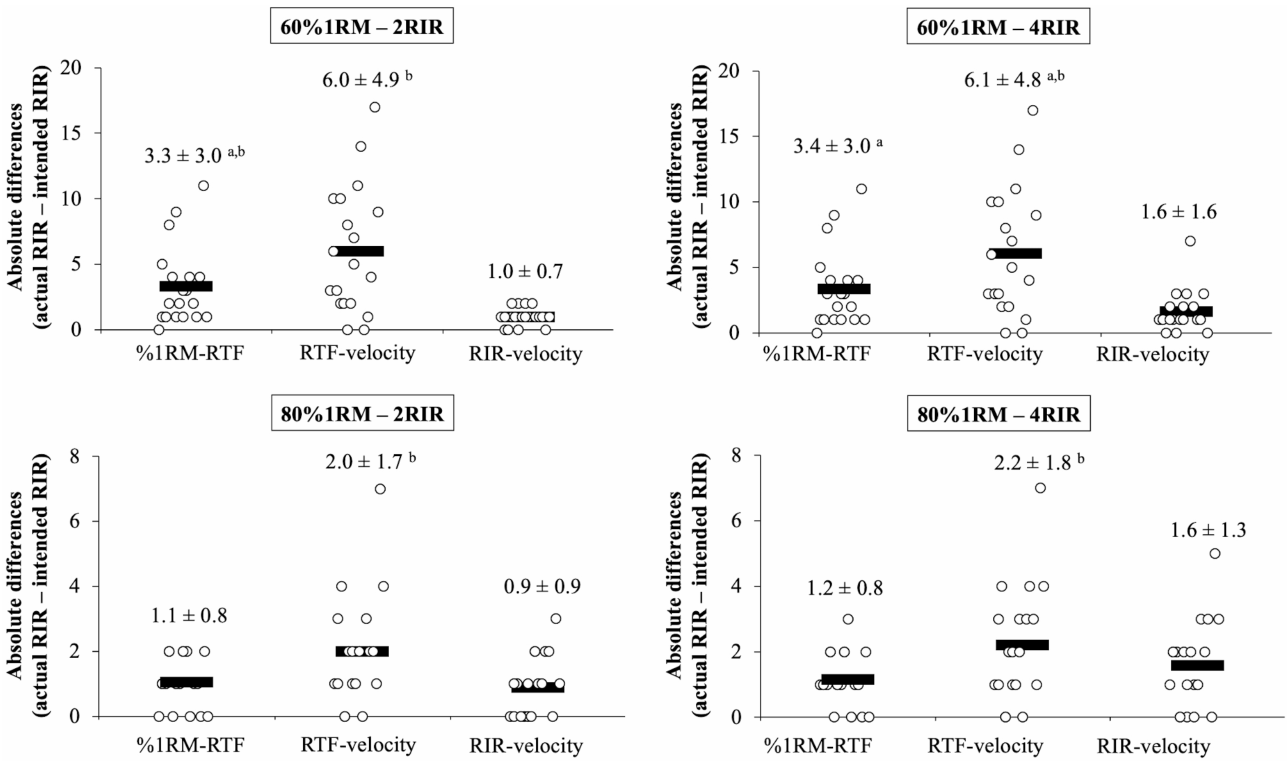

Fig. 2 Absolute differences between the actual and intended repetitions in reserve (RIR) for different prescription approaches (%1RM-RTF, RTF-velocity, and RIR-velocity) at two relative loads (60%1RM and 80%1RM) and two intended RIR targets (2RIR and 4RIR). Solid horizontal lines represent the mean absolute error for each approach, and individual data points are displayed. Letters "a" and "b" indicate significant differences ($p \le 0.05$) compared to the RTF-velocity and RIR-velocity relationships, respectively

of fixed %1RM-RTF prescriptions in real-world training scenarios.

To date, only one study has examined the general relationship between RTF and the fastest set velocity during the bench press. García-Ramos et al. [18] reported a standard error of the estimate of 3.6 repetitions, concluding that this level of error is unacceptable and necessitates determining individual RTF-velocity relationships for practical implementation. Unlike the %1RM-RTF relationship, the RTF-velocity approach offers the advantage of not requiring precise knowledge of the exact %1RM being lifted, allowing it to account for day-to-day variations in physical readiness. However, the higher accuracy of the %1RM-RTF relationship observed in this study compared to the RTF-velocity relationship may be partially attributed to the direct determination of 1RM 48 to 96 h prior to the main experimental session, ensuring greater precision in load selection. The low accuracy of the general RTF-velocity relationship observed here is not surprising, given the substantial variability among individuals, reported in previous studies, in the number of repetitions performed to failure when sets begin at the same velocity [18, 28]. This variability can be attributed to differences in muscular endurance and the fact that the same velocity corresponds to different %1RM values across individuals [29]. These factors underscore the limitations of a generalized RTF-velocity approach and the need for individualized data to enhance its practical utility in training.

The RIR-velocity relationship emerged as the most accurate method for estimating proximity to failure in this study. We used the standard velocity values proposed by Morán-Navarro et al. [8], who demonstrated that velocity at a given RIR does not vary across different loads (65%, 75%, and 85% of 1RM) or individual characteristics (novice, well-trained, and highly trained individuals). Notably, similar to findings for the RTF-velocity relationship [18, 19, 28], the only two studies comparing general and individual RIR-velocity relationships—one focused on the Smith machine bench pull [30] and the other on the free-weight back squat [20]—reported better accuracy with individualized relationships. This suggests that the accuracy observed in this study could be further improved by determining individual RIR-velocity profiles. Interestingly, no significant differences were found between the %1RM-RTF and RIR-velocity relationships at 80% 1RM, indicating that the advantages of general velocity thresholds for estimating proximity to failure could be dissipated at heavier loads. The key advantage of the RIR-velocity relationship, however, lies in its independence from knowing the exact %1RM being lifted, a factor often unknown in practice. However, the obvious limitation of the RIR-velocity relationship is that coaches need to have an accurate velocity measuring device. It is worth noting that unlike the %1RM-RTF relationship, the accuracy of RIR prediction with the RIR-velocity approach decreases when sets are terminated farther from failure. Overall, these findings suggest that while the general RIR-velocity relationship is the preferred method when individual relationships are unavailable, the accuracy of the %1RM-RTF relationship, when 1RM is precisely determined, is comparable for sets terminated farther from failure (e.g., 4RIR) at heavy loads (e.g., 80% 1RM).

A potential limitation of our study is that the bench press was performed using a Smith machine. While we employed the same linear velocity transducer (T-Force system) as the studies that proposed the general RTF-velocity and RIR-velocity relationships [8, 18], most of the studies included in Nuzzo et al.'s (2024) predictive tables were conducted with free-weight exercises. It remains unclear whether these relationships can be applied interchangeably between free-weight and Smith machine exercises. Additionally, although we analysed general %1RM-RTF, RTF-velocity, and RIR-velocity relationships, we did not explore the potential benefits of implementing individualized profiles. Such individualized relationships could improve the accuracy of all three approaches; however, it is unclear which would benefit most from this adaptation. Finally, our study was limited to a single exercise and specific relative loads (60% and 80% 1RM). Consequently, the generalizability of our findings to other resistance exercises or a wider range of loads is unknown. Future research should address these limitations by investigating free-weight exercises, different movement patterns, and the utility of individualized velocity-based and %1RM-RTF approaches across varied populations and training contexts.

Conclusions

This study highlights the general RIR-velocity relationship as the most accurate method for estimating proximity to failure during the Smith machine bench press when individual relationships are unavailable. The RIR-velocity relationship consistently aligned with the intended RIR without systematic differences and demonstrated the lowest absolute errors, particularly at lighter loads (60%1RM) and closer proximities to failure (2RIR). Notably, none of the participants reached failure before exceeding an MV of 0.27 $m \cdot s^{-1}$, demonstrating that, unlike the %1RM-RTF and RTF-velocity approaches, the RIR-velocity method consistently provided a reliable benchmark for avoiding training to failure. These findings emphasize the utility of the general RIR-velocity relationship as a practical and effective tool for prescribing resistance training, provided coaches have access to accurate velocity measurement devices during their athletes' training.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01098-2.

Supplementary Material 1

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Author contributions

XQ and AGR: study concept and design; AGR: data acquisition; XQ, BL and AGR: data analysis, interpretation, and article preparation. XQ, BL and AGR: critical revision of the article. All authors read and approved the final article.

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Data availability

The data and materials used to support the findings of the study are available within the following link: https://osf.io/3f7rt/files/osfstorage/674f2b141ee574e084f457ad.

Declarations

Ethics approval and consent to participate

The study was approved by the University of Granada Research Ethics Committee and provided with the following reference number: 2046/CEIH/2021. Participants provided informed consent after the risks and benefits of the study were explained.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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