Exercise type, training load, velocity loss threshold, and sets affect the relationship between lifting velocity and perceived repetitions in reserve in strength-trained individuals (#110432)

First revision

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Exercise type, training load, velocity loss threshold, and sets affect the relationship between lifting velocity and perceived repetitions in reserve in strength-trained individuals

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Purpose: To explore the relationship between bar velocity and perceived repetitions in reserve (pRIR) for the bench press and the squat exercises during multiple training sessions in strength-trained individuals.
Methods: Nineteen well-trained individuals (9♀ and 10♂, 26 ± 4 yr, 174 ± 8 cm, 74 ± 9 kg [mean ± standard deviation]) trained squats and bench press for six weeks. Within each week, they conducted three sessions with different loads, corresponding to ~ 77-79%, ~ 82-84%, and ~ 87-89% of 1 repetition maximum (1RM). The mean velocity was measured at the bar for all lifts, and the participants terminated each set based on a pre-set velocity loss threshold (20-60%). After every set termination, the participants reported pRIR.
Results: Based on 2972 unique measurements, we observed trivial to very large individual correlations between the objectively measured mean velocity and the pRIR (average r^2 = 0.3 for both squat and bench press). Type of exercise (squat or bench press), velocity loss threshold, load, and sets affected the pRIR for a given mean velocity. Sex (females vs. males) and training weeks were unrelated to pRIR.
Discussion and conclusion: Our findings suggest that mean bar velocity and pRIR provide complementary insights into strength training performance. However, since pRIR is influenced by exercise type, load, proximity to failure, and set number, these metrics should not be used interchangeably without careful consideration of these factors.

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Abstract

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Keywords: Strength training, rate of perceived exertion (RPE), exercise monitoring, squat, bench press

Introduction

Velocity-based strength training (VBST) has become a popular objective approach for managing exercise intensity/load and neuromuscular fatigue (Bastos et al., 2024; Jovanovic & Flanagan, 2014; Maroto-Izquierdo et al., 2022; Suchomel et al., 2021). Velocity-based strength training differs from traditional strength training, focusing on lifting velocity rather than loads in a percentage of 1 repetition maximum (1RM) or a given number of repetitions. Typically, VBST is based on the mean velocity of the bar (ascending phase), measured by devices such as a linear encoder or an accelerometer (Jovanovic & Flanagan, 2014; Weakley et al., 2021). A prerequisite with VBST – and using mean velocity as a variable – is maximal effort in the ascending phase of each repetition (Jovanovic & Flanagan, 2014).

It is well established that desired strength training outcomes rely on load intensity (e.g., % of 1RM) and volume (Atha, 1981). However, the effort in each lift (intention to move) and proximity to set failure can also be used to tune the adaptations to strength and power training (Grgic et al., 2022; Kawamori & Newton, 2006). While hypertrophy seems most efficiently acquired with (near) failure sets, non-failure sets are advocated as preferable for power and maximal strength development in well-trained individuals and athletes (Carroll et al., 2018). Indeed, controlling and limiting neuromuscular fatigue during exercise may enhance training quality and support specific adaptations (Izquierdo et al., 2006; Larsen et al., 2021; Suchomel et al., 2021).

As the mean velocity gradually declines with successive repetitions, a percentage loss of velocity or pre-set velocity threshold (in ms^{-1}) can be used to decide when to terminate the set. In practice, low velocity loss thresholds (i.e., <25%) appear preferred for developing muscle power and maximal strength, while hypertrophy seems to require higher velocity loss thresholds (>25%), i.e., close to contraction failure or RM (Baena-Marín et al., 2022; Hickmott et al., 2022; Weakley et al., 2021).

The mean velocity (ms^{-1}) has been demonstrated to correlate with both the percentage of 1RM and repetitions in reserve (RIR) (Pelland et al., 2022). Repetitions in reserve refer to the difference between the number of repetitions performed and the maximum possible repetitions in a set. However, it is evident that the relationship between mean velocity and RIR depends on the type of exercise, e.g., the bench press and the squat, and the high inter-individual variability seems to necessitate individual adjustments for practical application (Garcia-Ramos et al., 2018; Jukic et al., 2024; Moran-Navarro et al., 2019).

An alternative to objective measures of mean velocity is the subjective evaluation of effort and fatigue through the rate of perceived exertion (RPE) and perceived repetitions in reserve (pRIR) (Helms et al., 2016; Helms et al., 2020; Zourdos et al., 2016). The main argument for using RPE and pRIR is autoregulation, which is an individual, intuitive, and dynamic way to account for biological day-to-day variations and readiness to train (Suchomel et al., 2021). Perceived RIR is undeniably simplistic, practical, and low-cost, with no need for technological devices.

Both the objective mean velocity (Garcia-Ramos et al., 2018; Moran-Navarro et al., 2019) and subjective pRIR (Hickmott et al., 2024; Varela-Olalla et al., 2019) have been reported to predict the actual RIR in a set with acceptable accuracy. The pRIR seems, however, more influenced by the proximity to failure and training status than the objective, mean velocity measurements (Halperin et al., 2021; Moran-Navarro et al., 2019). That said, the applicability of the mean velocity method is also debatable, as some find good accuracy and reliability (Jukic et al., 2024), while others concluded that the mean velocity does not appropriately align with actual RIR values across loads and sets (Mansfield et al., 2023).

Previous studies examining the relationship between mean velocity, RIR, and pRIR have done so in controlled laboratory settings, using only a few test sessions (Garcia-Ramos et al., 2018; Jukic et al., 2024; Mansfield et al., 2022; Varela-Olalla et al., 2019). In such experimental settings, when several sets of multiple conditions are conducted in series (e.g., different loads and repetition ranges), the order and proximity of the conditions may affect the perceived efforts and ratings. First, the number of lifts and sets becomes restricted due to the development of neuromuscular fatigue; i.e., the total number of data points from each individual becomes limited. Second, the participants are, in fact, aware of the purpose of the study and may develop biased responses when assessing similarities or differences between the various conditions compared to real-world scenarios when the focus is on the training itself (the Hawthorne effect). This raises questions about the ecological validity of the available literature on the topic. An alternative approach is to collect mean velocity and pRIR data from consecutive real-life training sessions that vary in load intensity and proximity to failure.

This study explored how exercise type (bench press and squat), load intensity (% of 1RM), velocity loss thresholds, number of sets, and sex influence the relationship between objectively measured bar mean velocity and pRIR across multiple strength training sessions in well-trained individuals.

We recognize both VBST and pRIR as potentially valuable tools for managing exercise effort and training specificity, and our results may offer clearer insights into how these tools can be applied by individuals involved in strength training.

Methods

Participants

Nineteen well-trained young adults participated in this study (Table 1). Participants were classified as “advanced” to “highly advanced” resistance-trained individuals according to Santos et al. (2021). One male trained only the squat exercise, and one male trained only the bench press exercise due to shoulder and knee pains, respectively.

The inclusion criteria required volunteers to be young adults (< 40 years of age), have at least one year of consistent bench press and squat practice – including the past year, and demonstrate a minimum 1RM of 0.6 (females) or 1.0 (males) in the bench press and 1.0 (females) or 1.2 (males) in the squat.

After receiving written and oral information, all participants volunteered to take part in the study by signing an informed consent. The study was approved by the local ethical committee at the Norwegian School of Sport Sciences (103-290819).

*** Table 1. near here ***

Study design

The present study was based on data from a 6-week strength training period (18 sessions). The participants trained the bench press and the squat exercises in the same session. The mean velocity was tracked for all lifts. For the purpose of this study, we analyzed only the velocity of the last repetition in each set, along with the pRIR, which was recorded after each set.

After a 1RM test in bench press and squat, the participants were allocated to one of two groups. One group trained with a “low” velocity loss threshold (LVL), while the other group trained with a “high” velocity loss threshold (HVL). The training adaptations, such as changes in 1RM and local hypertrophy, to the LVL and HVL interventions are published elsewhere (Myrholt et al., 2023).

Of the 19 participants, four completed both the LVL and the HVL program, hence, seven males and four females completed the LVL program, and seven males and five females completed the HVL program. We used a Generalized Linear Mixed Model (GLMM) that allows for individual differences in the number of data points, ensuring that each participant's contribution is appropriately weighted in the analysis. Note that this study includes three more participants than those analyzed in Myrholt et al. (2023), and the raw data is available for download.

Rationale for the velocity thresholds and training volume

The LVL group trained with 20% and 30% mean velocity loss thresholds in squat and bench press, respectively (Table 2). The HVL group trained with 40% and 60% velocity loss thresholds in squat and bench press, respectively. These thresholds, which determined set termination once the velocity dropped below the specified percentage, were chosen based on previous studies (Pareja-Blanco et al., 2017; Pareja-Blanco et al., 2020; Sanchez-Medina & González-Badillo, 2011) and extensive pilot testing to ensure that the number of repetitions with the LVL program resulted in about half the number of repetitions per set as the HVL program (Table 2).

The training volume (total number of reps) between groups was matched, as the HVL trained with ~3 sets and the LVL trained with ~6 sets per exercise (Table 2). To achieve this, the HVL group was always three sessions ahead of the LVL group so that the LVL group's training volume could be adjusted weekly. Hence, we adjusted the number of sets per session for the LVL group to achieve approximately the same total number of repetitions as the HVL group.

Measuring mean velocity of the bar

A linear encoder tracked the duration (time, in seconds) and displacement (in meters) of the bar in all lifts (Musclelab, Ergotest; 200-Hz sampling rate and 0.019-mm resolution). The encoder was attached to the powerlifting bar on the right-hand side (10 cm outside the knurl mark). Care was taken to position the encoder to measure the vertical bar displacement. This was inspected in all sessions, and individual marks (tape) on the floor were used to ensure similar foot positioning from set to set in the squat. Similarly, the shoulder positioning and the placement of the encoder were individually adjusted in the bench press. A slight horizontal bar movement in the bench press is unavoidable, but care was taken to ensure the setup was similar for all sets at the individual level. All velocities are given as the mean velocity of the lifting (ascending) phase (calculated by Musclelab's proprietary software Ergotest, version 10.200.90.5097). The braking (descending) phase was not included in this study. Compared to 3D kinematic analyses of free-weight squats (Qualisys, sampled at 300 Hz), the coefficient of variation (CV) for mean velocity measurements is 1.9% (unpublished data from our laboratory).

Perceived repetitions in reserve

Prior to the training period, the participants were informed about the concept of RIR and pRIR. They were instructed to verbally express their pRIR immediately after each set. The researchers recorded the pRIR alongside the mean velocity of the last repetition.

Training

Strength training sessions were conducted using free-weight Eleiko equipment.

As a general warm-up, five minutes of stationary cycling at 80-120 W (Keiser M3i Lite, Keiser Sport) was followed by 5-10 minutes of dynamic shoulder mobility.

The individual training loads for the training sessions were determined by pre-planned target velocities (Table 2). Loads (kg) were adjusted to achieve the pre-planned mean velocity with a maximal deviation of 0.03 ms^{-1}. This was typically achieved by 1-3 single repetition sets with maximal effort in the ascending phase. To exemplify, if the target velocity was 0.53 ms^{-1} a load (kg), a velocity of 0.50-0.56 was acceptable. Based on pre-set velocities, the velocity thresholds for set termination were determined (this was thus different for the LVL and HVL groups). Both groups conducted the same training sessions, with three sessions per week featuring “low,” “moderate,” and “heavy” loads (Table 2).

Both the bench press and the squat exercise were executed in accordance with the rules of powerlifting (www.powerlifting.sport), and stance and grip width and range of motion were individually standardized across the 18 training sessions. All sessions were supervised to ensure proper lifting techniques, and real-time feedback was given to participants. Sets were terminated if improper techniques were observed. An experienced spotter was present to ensure the lifter's safety, but the spotter did not interfere with the lifts unless unexpected failure or perceived risk of injury. Interrupted sets were rare and not included in the data material presented.

Statistics

All analyses and presentations are done with pRIRs from 0 to 4 to ensure sufficient statistical power at each pRIR value. 145 measurements with pRIR >4 were excluded (4.7% of the total data points). The excluded pRIR data points ranged from 5 to 12, and when divided by group, session (load), and sex, the number of data points per pRIR (5-12) was very low.

Pearson's r was used to calculate correlations between variables. The association between mean velocity and pRIR was calculated for each participant and then averaged for grouped values.

Effect sizes (ES) were estimated using Cohen’s d, and the following scale was used: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, 2.0-4.0 very large. For correlations, the following scale was used: 0.1-0.3 small, 0.3-0.5 moderate, 0.5-0.7 large, 0.7-0.9 very large (Hopkins et al., 2009).

A Generalized Linear Mixed Model (GLMM) was employed to assess the relationship between mean velocity and pRIR, accounting for repeated measurements and individual variability. The model included fixed effects for exercise type (bench press, squat), velocity group (LVL, HVL), load, sets per session, sex (female, male), and training week. Additionally, interaction terms between exercise type and velocity group were included to evaluate whether the relationship between velocity and pRIR varied by exercise type. To capture between-subject variability, the model incorporated random intercepts and random slopes for each participant. The random intercepts accounted for individual differences in baseline pRIR, while random slopes for mean velocity allowed individuals to vary in their response to velocity. The correlation between random intercepts and slopes was estimated to assess whether participants with higher baseline pRIR responded differently to changes in velocity. Residual variance accounted for within-subject fluctuations, representing variation in pRIR that the fixed or random effects did not explain. The model was estimated using Restricted Maximum Likelihood (REML), ensuring appropriate weighting of individuals contributing varying numbers of data points while preventing bias. Model estimates were reported with 95% confidence intervals, and statistical significance was set at $p < 0.05$.

The data was organized and analyzed using Python (version 3.11) with Panda's package (version 2.2.2). Plots and visualizations were created using Matplotlib (version 3.9.2) and Seaborn (version 0.13.2). The GLMM was implemented in R (version 4.4.2) using the lme4 package.

Results

A total of 2972 mean velocity and pRIR combinations were analyzed. Table 2 presents a summary of the number of lifts differentiated by exercise, velocity loss group (LVL and HVL), sex (male and female), and type of session (low, moderate, or high loads).

*** Table 2 and Figure 1 near here ***

The individual regression lines in Figure 1 depict the relationship between mean velocity and pRIR (measured per set) for each participant. For the squat exercise, the correlation coefficients (r-values) between mean velocity and pRIR ranged from 0.3 to 0.9, with an average correlation of 0.6 ± 0.2 (mean ± standard deviation) across participants. For the bench press, the individual correlations ranged from 0.1 to 0.9, with an average correlation of 0.6 ± 0.2.

In Figures 2-8, pRIR is plotted as a function of mean velocity. The data is differentiated on exercise, velocity group (LVL vs. HVL), type of session (low, moderate, and high load), and sex. Table 3 gives an overview of the number of data points for the different plots.

*** Figure 2-8 near here ***

*** Table 3. near here ***

The GLMM analysis (Table 4) revealed that the mean velocity was strongly associated with pRIR ($\beta = 6.99$, $p < 0.001$), indicating that faster movements correspond with higher pRIR values. Group (LVL vs. HVL) was the second strongest predictor ($\beta = 0.94$, $p < 0.001$), suggesting that individuals in the HVL group tend to report higher pRIR. Exercise type demonstrated a negative effect ($\beta = -0.67$, $p < 0.001$), meaning that the bench press was associated with lower pRIR values than the squat. The interaction between group and exercise type was significant and negative ($\beta = -0.33$, $p < 0.001$), which suggests that the difference in pRIR between squat and bench press was smaller in the HVL group than in the LVL group. Additionally, the number of sets per session was inversely related to pRIR ($\beta = -0.11$, $p < 0.001$). Weeks of training ($\beta = -0.01$, $p = 0.27$) and sex ($\beta = 0.35$, $p = 0.26$) did not significantly affect pRIR. The random effects revealed considerable between-subject variability, with a standard deviation of 0.96 for the intercept and 2.25 for the slope of mean velocity and a strong negative correlation ($r = -0.73$) between these random components. The within-subject residual variability was 0.69.

*** Table 4. here near ***

Discussion

This study explored the relationship between mean velocity of the bar and pRIR across a 6-week training period, analyzing nearly 3000 data points. The key findings were: 1) The mean velocity was strongly associated with pRIR but with individual differences from trivial to very large correlations. 2) The type of exercise, i.e., bench press and squat, the pre-set velocity loss thresholds (LVL or HVL), the session load (% of 1RM), and the number of sets influenced the relationships between bar velocity and pRIR. 3) The pRIR was not appreciably influenced by sex and the number of training weeks.

Perceived or predicted RIR (pRIR) is a subjective variable with inherent biases (Hackett et al., 2017; Hackett et al., 2012; Helms, Brown, et al., 2017). Hackett et al. (2012) observed that the participants tended to underestimate actual RIRs in the first sets (sets 1 and 2) but more accurately predicted RIR in the later sets (sets 3 and 4). Hackett et al. (2017) reported an accuracy of ~1 repetition when the actual RIR was 0-5, while the inaccuracy increased to >2 repetitions with an actual RIR of 7-10. These observations were supported by Zourdos et al. (2021). In our study, pRIRs were <5, suggesting that participants likely demonstrated acceptable RIR estimation accuracy. In support of this, the GLMM analysis showed a within-subject residual variability of 0.69, indicating that the participants' reported pRIR values, on average, deviated from the model's predictions by less than one repetition.

All participants reported lower pRIR for a given mean velocity in the squat than in the bench press. This aligns with observations that 1RM is achieved with a significantly lower mean velocity in the bench press than in the squat (Gonzalez-Badillo & Sanchez-Medina, 2010; Helms, Storey, et al., 2017; Iglesias-Soler et al., 2019; Zourdos et al., 2016). Consequently, the bar velocity-repetition maximum (RM) relationship and, in turn, the velocity-pRIR relationship for squats are shifted to higher mean velocities than for bench press (Iglesias-Soler et al., 2019). The greater range of motion and bar displacement, combined with the sticking point occurring earlier in the lift (ascending phase) of the squat compared to the bench press (Kompf & Arandjelović, 2017), may cause a higher mean velocity for a given percentage of 1RM.

In the present study, about half of the participants trained with low bar velocity loss thresholds (LVL) for terminating each set (i.e., 20% for squat and 30% for bench press), while the other half trained with high bar velocity loss thresholds (HVL: 40% in the squat and 60% in the bench press) – i.e., close to contraction failure in each set. Visual inspection of Figures 3 and 4 shows that the HVL group reported higher pRIR values for a given mean velocity than the LVL group, which was most pronounced for the bench press exercise. This finding was confirmed by the GLMM, which detected a significant group effect of about one pRIR and an interaction effect between exercise type and velocity group. By design, the LVL group terminated the sets at higher mean velocities than the HVL group, meaning the LVL group was likely to underestimate the RIR. This suggestion aligns with observations from previous studies (Hackett et al., 2012; Zourdos et al., 2019), which have shown systematically more accurate RIR prediction closer to failure. Nonetheless, it remains possible that the HVL group overestimated their RIR.

Our participants conducted three different sessions per week, consisting of low-, medium-, and high-load sessions (Table 2). We observed a clear load effect on pRIR, with low and moderate loads resulting in lower pRIR values at a given mean velocity compared to heavy loads. This was evident for both exercises, especially for the squat (Figures 7 and 8). Interestingly, the sensation and experience of effort and exertion seem to depend on several factors, including neural drive from the motor cortex, which increases with higher muscle force requirements, and neuromuscular fatigue (Pageaux, 2016). Heavy loads challenge the lifter's maximal capacity, where even minimal fatigue can lead to failure. In contrast, lighter loads allow for continued repetitions despite severe neuromuscular fatigue (Behm et al., 2002). Thus, the sensation of muscle fatigue and discomfort (Pollak et al., 2014) might lead to an underestimation of RIR with lower loads. Alternatively, the participants were overly optimistic in their RIR predictions with heavy loads due to low muscular fatigue and discomfort, "it just feels heavy". In correspondence with this, Mansfield et al. (2023) observed an effect of load (60% vs. 80% of 1RM) in the prediction (estimates) of RIR in the bench press, where the mean velocity at 0-3 RIR was higher with 60% of 1RM load than with 80% of 1RM. Physiologically, this suggests that neuromuscular fatigue during low loads, probably due to more repetitions, causes a steeper decline in mean velocity during the final repetitions of a set compared to heavier loads with fewer total repetitions (maybe there is a non-linear drop in velocity).

Mansfield et al. (2023) observed that RIR decreased with each successive set. We found the same; for a given mean velocity, the pRIR was lower in, for example, the third set compared to the first. In other words, as neuromuscular fatigue accumulated over the sets, the participants became less optimistic about their RIR's for a given mean velocity. However, this effect was rather small, accounting for about -0.1 RIR per set (according to the GLMM analysis).

We observed that the correlations between mean velocity and pRIR varied considerably at the individual level, but no systematic improvements (changes) in the relationship between the mean velocity and the pRIR occurred during the 6-week training period, inferring that the participants did not improve (or worsen) their RIR prediction accuracy. This finding is in agreement with recent studies (Halperin et al., 2021; Jukic et al., 2024; Remmert et al., 2023) that revealed no apparent effects of training status (experience) on the accuracy of RIR prediction. However, it would be intriguing to see if individuals with poor correlations between bar velocity and pRIR could improve by deliberate practice – as no feedback was given during the training period in the current study.

Subjective assessments of effort and exertion (such as RPE and RIR) are reported to be practically similar between sexes across different modes of exercise and exertion (Losnegard et al., 2021; Morishita et al., 2018; Naclerio & Larumbe-Zabala, 2017a, 2017b). This is in line with our observations; the effect of sex was not significant in the GLMM analysis. From visual inspection of Figures 5 and 6, we can, however, see a trend where the females recorded higher pRIR values at a given bar velocity. Accordingly, Odgers et al. (2021) observed lower bar velocities in females than males at 7-9 RPE (corresponding to 1-3 RIR) in the front squat exercise but not in the hexagonal bar deadlift exercise. Moreover, Naclerio and Larumbe-Zabala (2017b) observed no sex difference in squats in strength-trained athletes. Generally, females demonstrate similar or better neuromuscular endurance than males, which might, at least partly, be related to absolute lower strength and an on average higher distribution of type I fiber in females than males (Hunter, 2009). Note, however, that we had a limited number of participants (both females and males), causing a risk of missing a potential sex effect.

The main limitation of the present study was that we did not measure the actual RIR at any point, only pRIR. Thus, we cannot know how precise the participants were in their RIR estimations. Moreover, our participants rarely reported more than 4 RIR, meaning that our study was restricted to this number of pRIR (0-4). Nevertheless, together with observations of others (Hackett et al., 2012; Zourdos et al., 2019), it seems reasonable to suggest that the limit for accurate RIR estimations is around five. A caveat is that we assume that the relationship between bar velocity and RIR is linear, which is probably not universally applicable across individuals (Jukic et al., 2024).

Another potential limitation is that we used the mean velocity. It could be that mean propulsion velocity (the mean velocity of the accelerations phase) and/or the lowest/minimum velocity had resulted in different results and should be further investigated; however, with the loads used in the present study (~77-89% of 1RM), the differences between mean propulsion and mean velocities of the whole movement should be very small or neglectable (Sanchez-Medina et al., 2017; Sanchez-Medina et al., 2010).

Despite its limitations, the present study has high ecological validity by virtue of an extensive data set from actual training sessions conducted by well-strength-trained individuals. Moreover, all sessions were supervised. The inclusion of both sexes and different pre-set velocity loss targets (low and high), as well as sessions with different loads (low, medium, and heavy) in both bench press and squat (an upper and a lower body exercise), provided us with several interesting observations that allude to important nuances to be aware of when applying VBST and pRIR in training.

Practical implications

Different strength exercises, e.g., bench press and squat, exhibit distinct velocity-RIR profiles at the individual level. Mean velocity and pRIR are complementary but not interchangeable methods, as also noted by Mansfield et al. (2023). Consequently, training sessions managed by VBST or pRIR may differ, even when the intended session goal is the same. However, we do not assert that one method is superior to the other, as both have advantages and limitations. For power development and maximal strength training, VBST offers a key advantage over pRIR, as higher RIR values can compromise estimation accuracy, and bar velocity is directly relevant for assessing performance and training quality via biofeedback (Weakley et al., 2021). In contrast, pRIR may be equally effective or even preferable for hypertrophy-focused training, particularly when working within 0–2 RIR (Grgic et al., 2022; Halperin et al., 2021; Suchomel et al., 2021). Combining both methods may provide optimal benefits for high-level athletes, whereas RIR alone is likely sufficient for beginners, recreational lifters, and non-athlete populations, such as patients (Bastos et al., 2024; Maroto-Izquierdo et al., 2022). Further research across diverse populations is needed to better evaluate the advantages of VBST compared to or in combination with pRIR, given that pRIR is cost-free and easy to implement.

Conclusion

In this study, we investigated the relationship between mean velocity of the bar and pRIR during multiple exercise sessions. We conclude that type of exercise (bench press and squat), load (in %RM), the number of sets, and the proximity to failure (velocity loss threshold), but not sex and the number of training weeks, influenced the relationships between mean bar velocity (of the ascending phase) and pRIR. Both mean velocity and pRIR can be used to manage strength training, but these metrics may not be used interchangeably. We recommend using VBST in conjunction with pRIR for optimal control during strength training.

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Figure 1

Individual regression lines for the correlation between average concentric velocity for each reported value of perceived repetitions in reserve.

Individual regression lines for the correlation between average concentric velocity ($m \cdot s^{-1}$) for each reported value of perceived repetitions in reserve (pRIR). The blue lines represent the bench press, and the orange represents the squat. The thick lines represent the mean of the individual lines for each exercise.

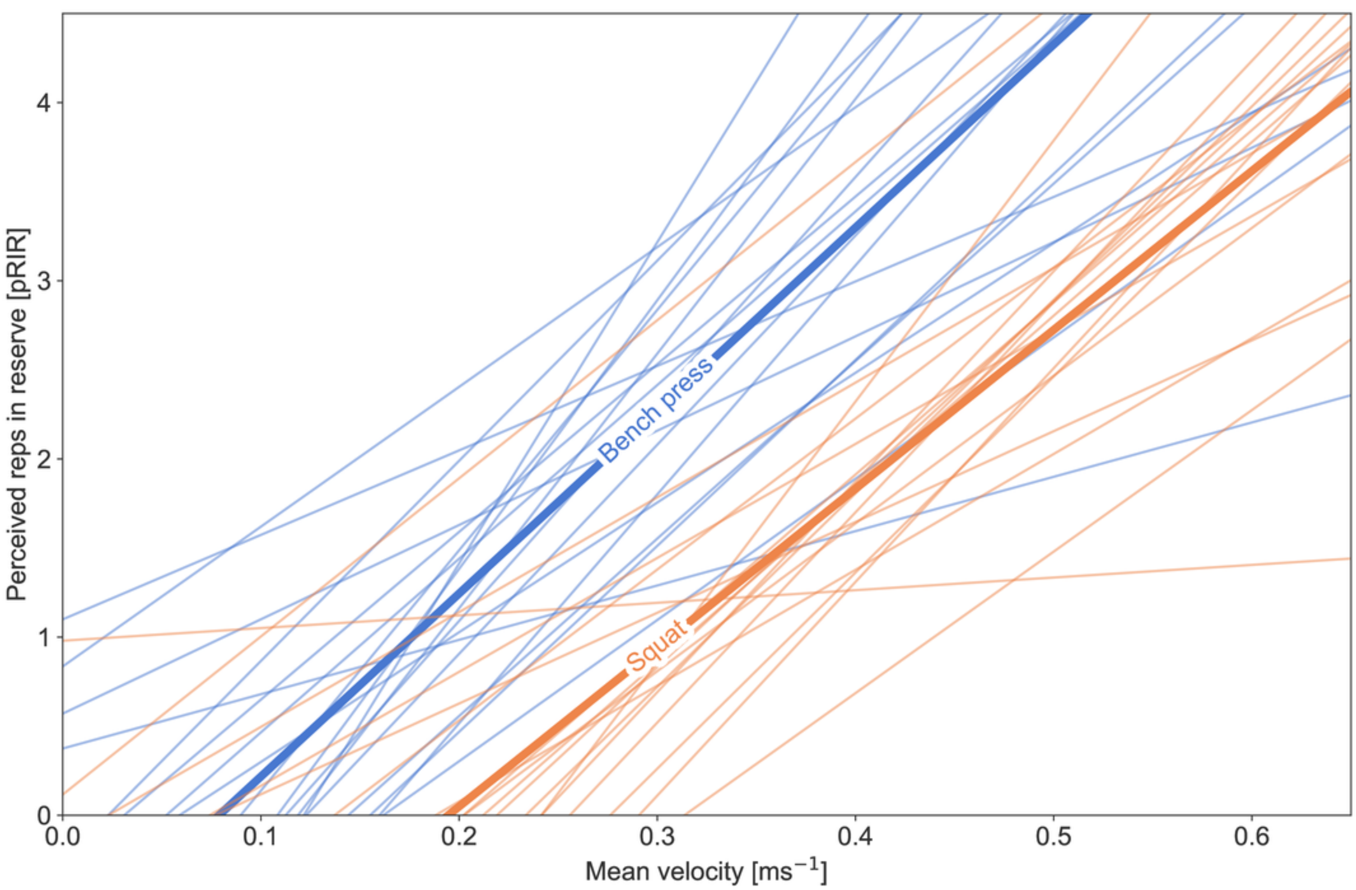

Figure 2

Average concentric velocity and perceived repetitions in reserve for the bench press and the squat.

Kernel density estimation plots of average concentric velocity ($m \cdot s^{-1}$) for each reported value of perceived repetitions in reserve (pRIR). Comparison of exercise; bench press (blue) vs. squat (orange). Error bars are 95% confidence intervals around the mean. d = Cohen's d, effect size for the difference.

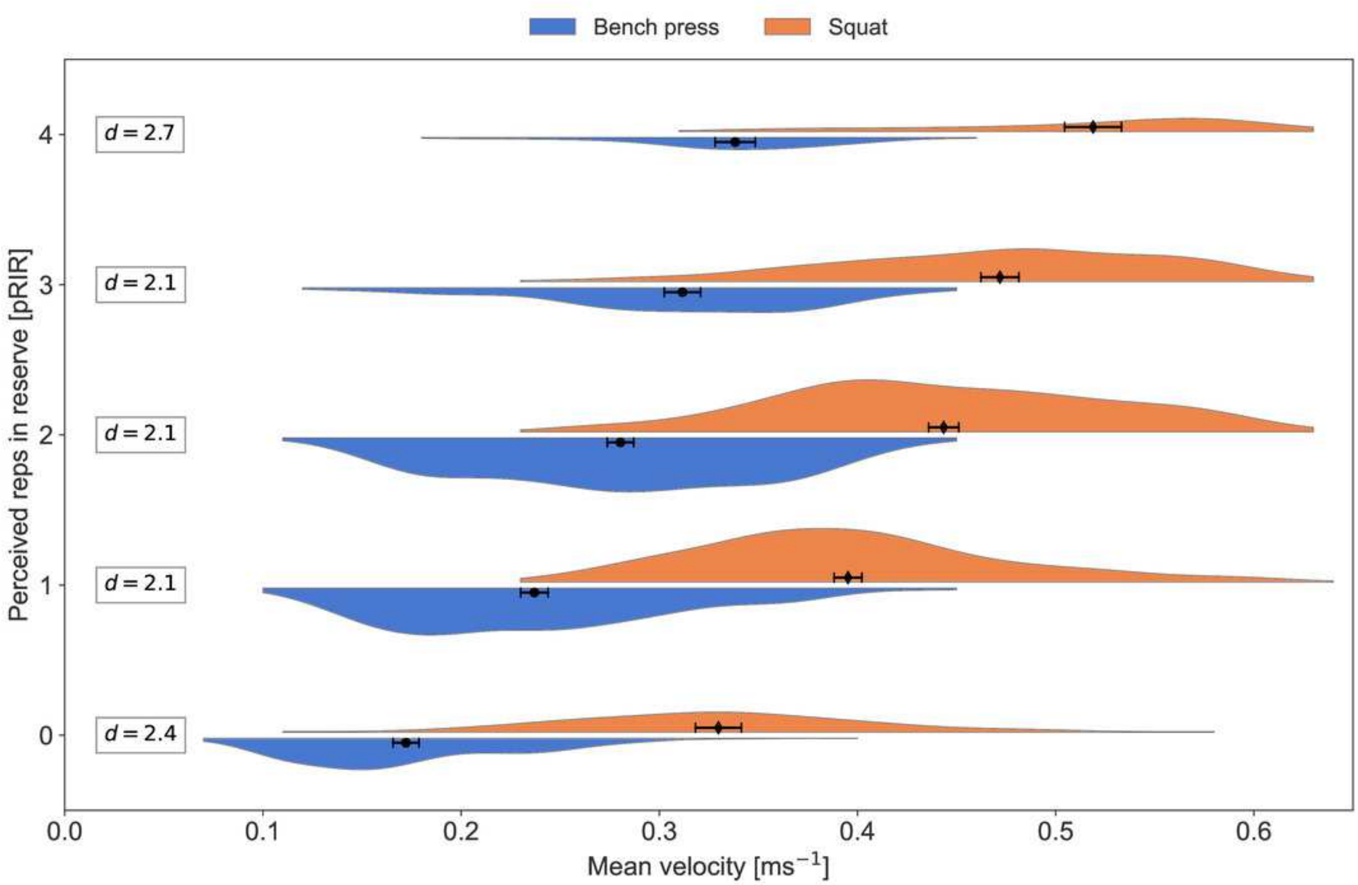

Figure 3

Average concentric velocity and perceived repetitions in reserve in the bench press for the low- and high-velocity-loss group.

Kernel density estimation plots of average concentric velocity ($m \cdot s^{-1}$) for each reported value of perceived repetitions in reserve (pRIR) in **bench press**. Comparison of pre-set velocity loss threshold group; low-velocity-loss group (blue) vs. high-velocity-loss group (orange). Error bars are 95% confidence intervals around the mean. d = Cohen's d, effect size for the difference.

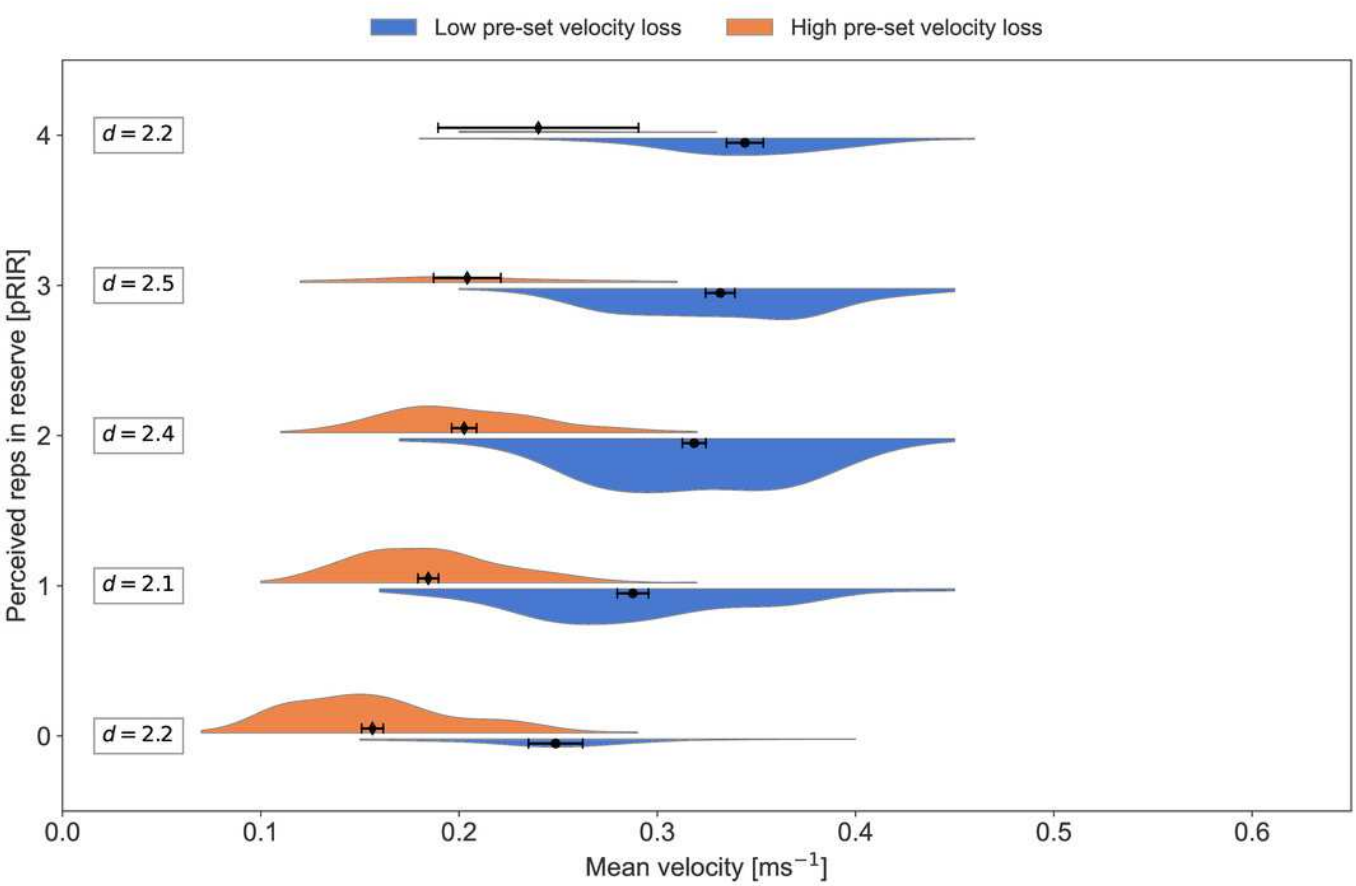

Figure 4

Average concentric velocity and perceived repetitions in reserve in the squat for the low- and high-velocity-loss group.

Kernel density estimation plots of average concentric velocity ($m\cdot s^{-1}$) for each reported value of perceived repetitions in reserve (pRIR) in **squat**. Comparison of pre-set velocity loss threshold group; low-velocity-loss group (blue) vs. high-velocity-loss group (orange). Error bars are 95% confidence intervals around the mean. d = Cohen’s d, effect size for the difference.

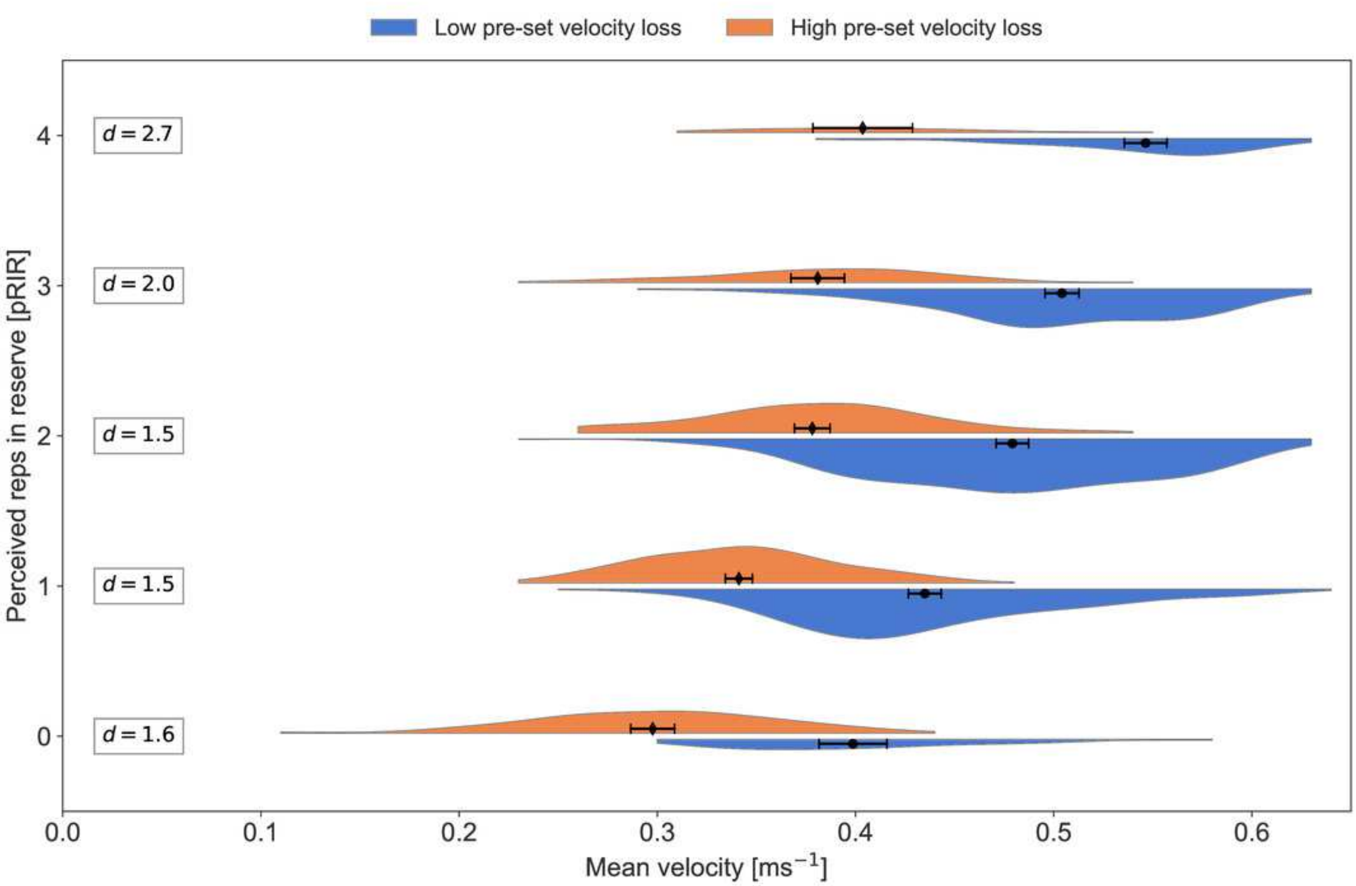

Figure 5

Average concentric velocity and perceived repetitions in reserve for the bench press in males and females.

Kernel density estimation plots of average concentric velocity (m·s^{-1}) for each reported value of perceived repetitions in reserve (pRIR) in **bench press**. Comparison of sex; males (blue) vs. females (orange). Error bars are 95% confidence intervals around the mean. d = Cohen's d, effect size for the difference.

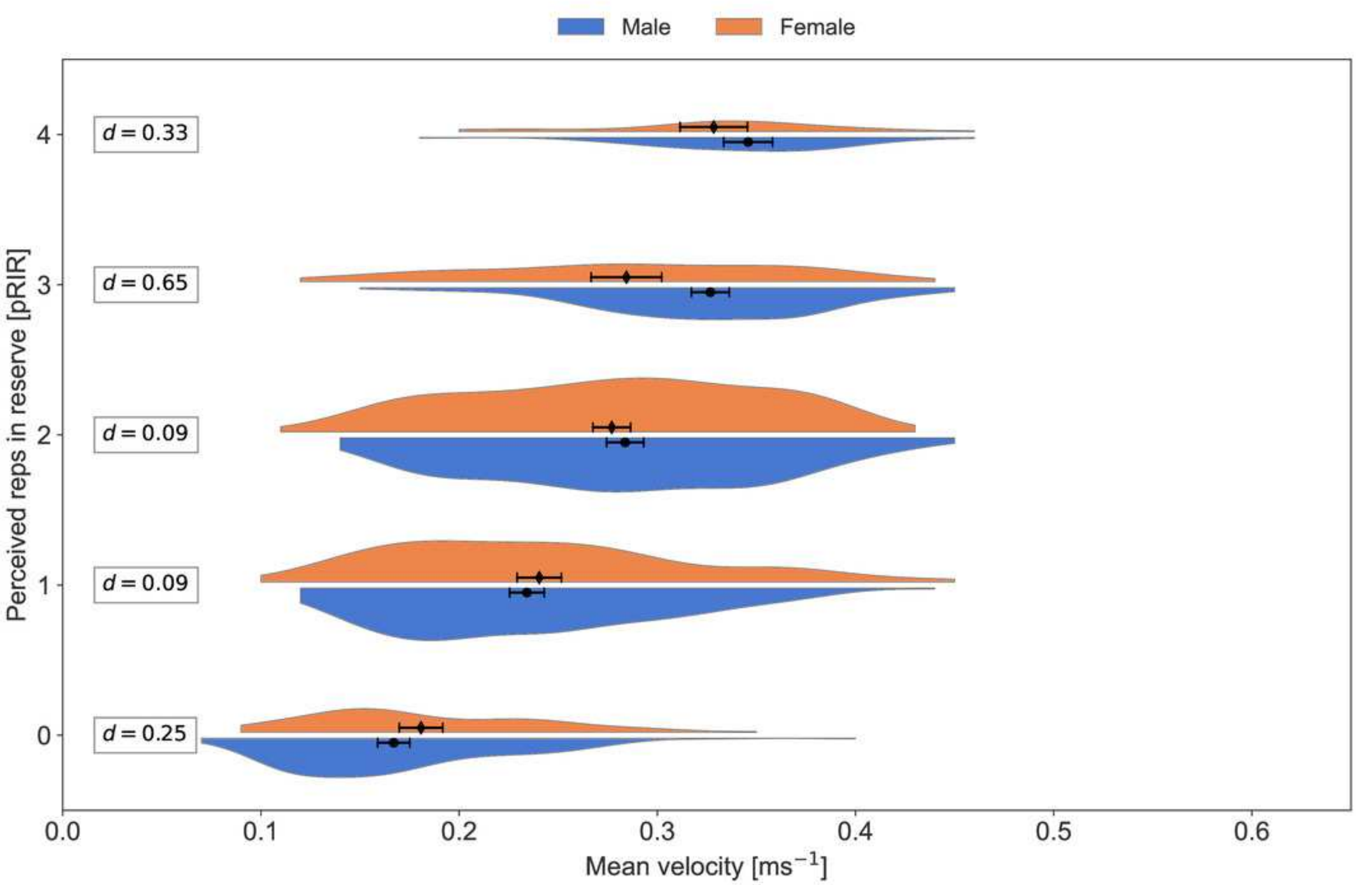

Figure 6

Average concentric velocity and perceived repetitions in reserve for the squat in males and females.

Kernel density estimation plots of average concentric velocity (m·s^{-1}) for each reported value of perceived repetitions in reserve (pRIR) in **squat**. Comparison of sex; males (blue) vs. females (orange). Error bars are 95% confidence intervals around the mean. d = Cohen's d, effect size for the difference.

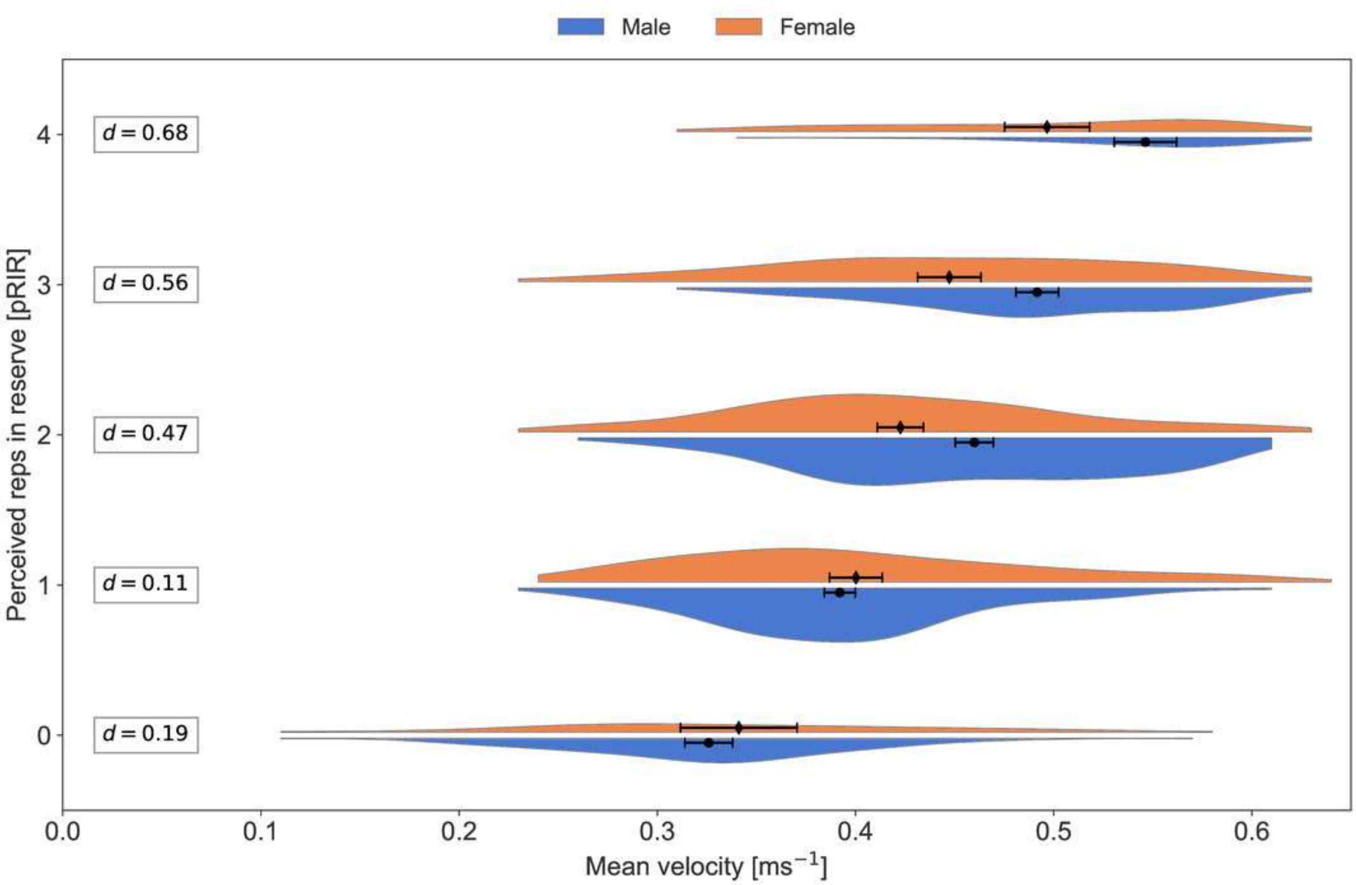

Figure 7

Average concentric velocity and perceived repetitions in reserve in the bench press with different training loads.

Box plots showing median, lower, and upper quartiles of average concentric velocity ($m \cdot s^{-1}$) for each reported value of perceived repetitions in reserve (pRIR) in **bench press**. Comparison of loads in % of 1 repetition maximum; low (79% = 0.53 m/s, blue), moderate (0.45 m/s, orange), and high (0.38 m/s, green). Error bars are 95% confidence intervals around the mean.

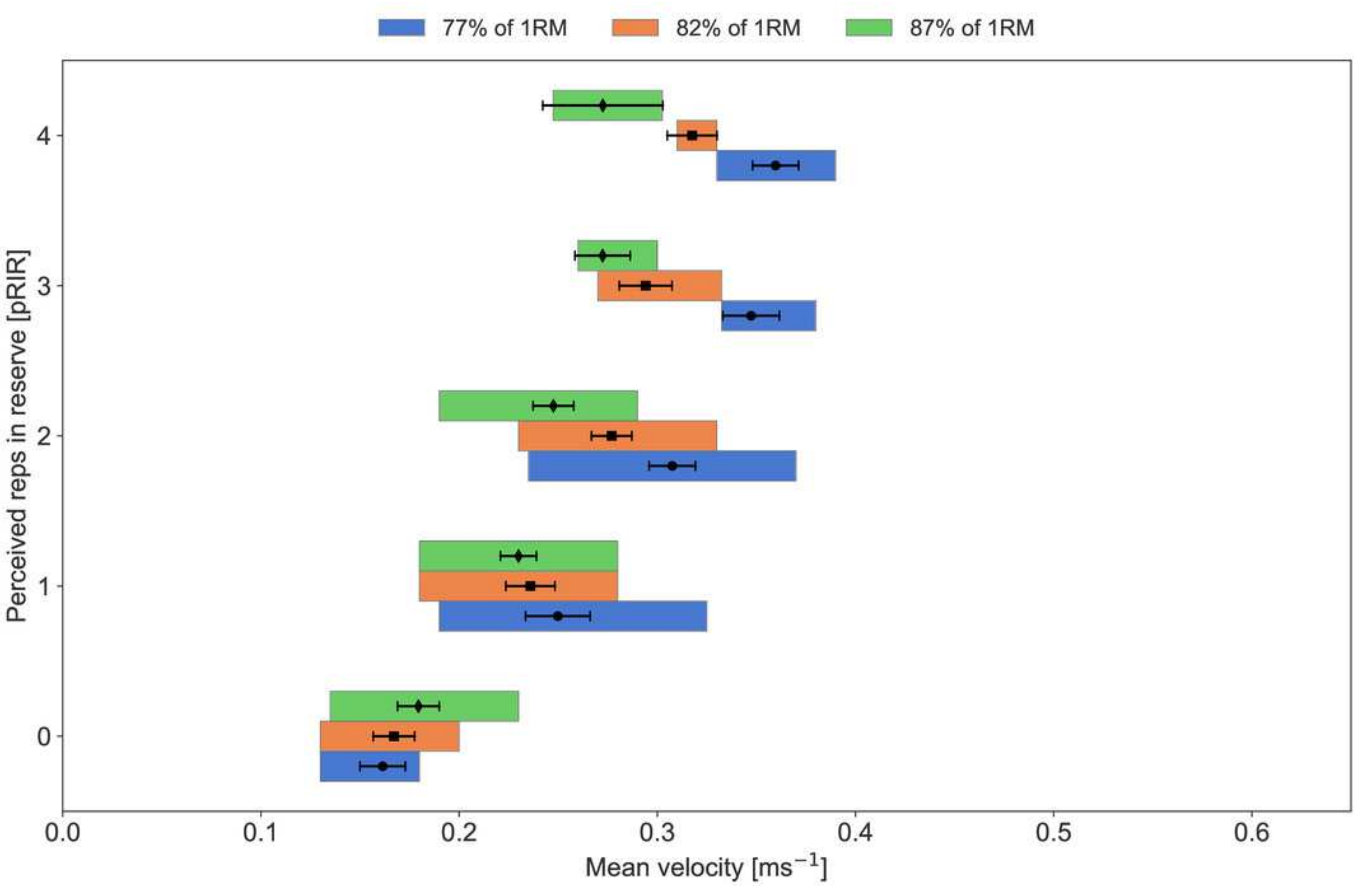

Figure 8

Average concentric velocity and perceived repetitions in reserve in the squat with different training loads.

Box plots showing median, lower, and upper quartiles of average concentric velocity ($m \cdot s^{-1}$) for each reported value of perceived repetitions in reserve (pRIR) in **squat**. Comparison of loads in % of 1 repetition maximum; low (79% = 0.70 m/s, blue), moderate (84% = 0.45 m/s, orange) and high (89% = 0.38 m/s, green). Error bars are 95% confidence intervals around the mean.

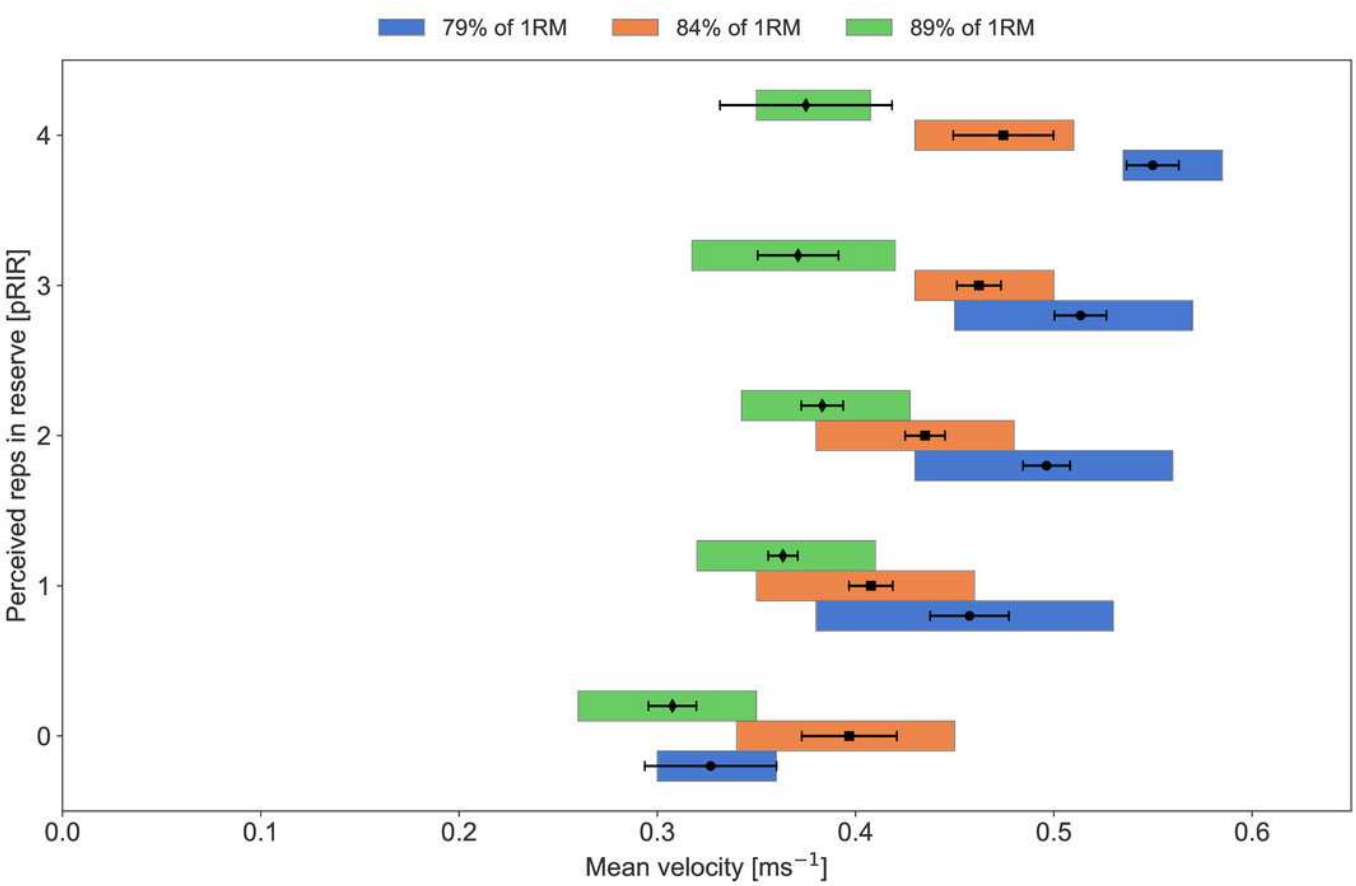

Table 1 (on next page)

Baseline data.

Baseline data.

	Females (n=9)			Males (n=10)		
	Mean ± SD			Mean ± SD		
Age (years)	26	±	5	26	±	3
Height (cm)	169	±	6	178	±	6
Body weight (kg)	67	±	7	81	±	5
Squat 1RM (kg)	86	±	18	141	±	16
Bench press 1RM (kg)	51	±	7	114	±	11

1RM: 1 repetition maximum; SD: standard deviation

Table 2(on next page)

Descriptive data of the training sessions.

Descriptive data of the training sessions. Data are presented for the bench press and squat. The columns represent the three sessions conducted with different loads defined by bar velocity. The rows represent the two groups that trained with either low- or high-velocity-loss thresholds (LVL: bench press 30% and squat 20%; HVL: bench press 60% and squat 40%).

	Bench press			Squat		
	Low load 0.53 ms^{-1} ~77% of 1RM	Moderate load 0.45 ms^{-1} ~82% of 1RM	Heavy load 0.38 ms^{-1} ~87% of 1RM	Low load 0.70 ms^{-1} ~79% of 1RM	Moderate load 0.60 ms^{-1} ~84% of 1RM	Heavy load 0.49 ms^{-1} ~89% of 1RM
Number of reps per set						
LVL	4.7 ± 1.6	3.9 ± 1.5	2.7 ± 1.2	4.2 ± 2.0	3.2 ± 1.5	2.1 ± 1.2
HVL	9.5 ± 3.2	7.9 ± 3.1	6.0 ± 2.4	9.5 ± 4.2	7.0 ± 3.2	5.1 ± 2.4
Number of sets per session						
LVL	6.0 ± 1.1	5.3 ± 1.1	5.3 ± 1.6	5.9 ± 2.4	5.4 ± 1.8	5.5 ± 1.8
HVL	3.0 ± 0.2	3.1 ± 0.3	2.9 ± 0.4	2.9 ± 0.3	3.0 ± 0.3	3.0 ± 0.3
pRIR						
LVL	2.6 ± 1.0	2.2 ± 1.0	1.5 ± 1.0	2.6 ± 1.0	2.0 ± 1.0	1.4 ± 0.9
HVL	1.6 ± 0.9	1.3 ± 0.9	1.2 ± 0.9	2.2 ± 1.0	1.9 ± 1.0	1.2 ± 1.0
Velocity loss (%)						
LVL	31.3 ± 7.4	31.8 ± 8.5	31.2 ± 10.9	21.2 ± 5.2	22.0 ± 6.3	21.3 ± 8.0
HVL	61.5 ± 7.5	59.5 ± 8.4	55.8 ± 10.7	41.3 ± 6.5	40.3 ± 6.0	39.6 ± 8.2
Velocity (ms^{-1})						
LVL	0.36 ± 0.04	0.31 ± 0.04	0.27 ± 0.04	0.55 ± 0.04	0.48 ± 0.04	0.40 ± 0.04
HVL	0.20 ± 0.04	0.18 ± 0.04	0.17 ± 0.04	0.40 ± 0.05	0.36 ± 0.04	0.30 ± 0.04

1RM: 1 repetition maximum; HVL: high-velocity-loss threshold group; LVL: low-velocity-loss threshold group; pRIR: perceived repetitions in reserve

Table 3(on next page)

Overview of correlation analyses.

Overview of correlation analyses presented in Figure 2-8. The x-axis is either absolute velocity (ms^{-1}) in the final repetition of the set or the percentage (%) loss in velocity. The data are filtered for exercise, sex, group (LVL, HVL), and session (low, moderate, or high loads).

Figure	Exercise	Filter	X-axis	Y-axis	N
2	Both	Exercise; bench press vs. squat	Mean velocity (ms^{-1})	RIR; 0-4	1476 vs. 1496
3	Bench Press	Velocity group; LVL vs. HVL	Mean velocity (ms^{-1})	RIR; 0-4	853 vs. 623
4	Squat	Velocity group; LVL vs. HVL	Mean velocity (ms^{-1})	RIR; 0-4	921 vs. 575
5	Bench Press	Sex; female vs. male	Mean velocity (ms^{-1})	RIR; 0-4	835 vs. 641
6	Squat	Sex; female vs. male	Mean velocity (ms^{-1})	RIR; 0-4	881 vs. 615
7	Bench Press	Session loads; low (0.53 ms^{-1}) vs. moderate (0.45 ms^{-1}) vs. high (0.38 ms^{-1})	Mean velocity (ms^{-1})	RIR; 0-4	490 vs. 484 vs. 502
8	Squat	Session loads; low (0.70 ms^{-1}) vs. moderate (0.60 ms^{-1}) vs. high (0.49 ms^{-1})	Mean velocity (ms^{-1})	RIR; 0-4	465 vs. 512 vs. 519

N: number of data points; HVL: high-velocity-loss threshold group; LVL: low-velocity-loss threshold group; RIR: repetitions in reserve.

Table 4(on next page)

Generalized Linear Mixed Model analysis.

Generalized Linear Mixed Models with perceived repetitions in reserve (pRIR) as the dependent variable.

Predictor of pRIR	Effects	Coefficient (β)	Std. error	z-value	p-value	95% Confidence interval
Intercept (i.e., when mean velocity is 0)	Fixed	-0.59	0.27	-2.2	0.04	[-1.15, -0.03]
Mean velocity (ms^{-1})	Fixed	6.99	0.59	11.8	0.00	[5.77, 8.21]
Group (LVL vs. HVL)	Fixed	0.94	0.07	14.2	0.00	[0.81, 1.07]
Exercise (squat vs. bench press)	Fixed	-0.67	0.07	-9.8	0.00	[-0.80, -0.53]
Sex (female vs. male)	Fixed	0.35	0.30	1.2	0.26	[-0.29, 0.99]
Load (low vs. high)	Fixed	0.35	0.04	8.3	0.00	[0.27, 0.43]
Interaction: LVL vs. HVL x squat vs. bench press	Fixed	-0.33	0.07	-4.9	0.00	[-0.46, -0.19]
Load (moderate vs. high)	Fixed	0.23	0.03	6.8	0.00	[0.17, 0.30]
Sets (number of sets for each exercise per session)	Fixed	-0.11	0.01	-14.1	0.00	[-0.12, -0.09]
Week (1-6 of the training period)	Fixed	-0.01	0.01	-1.1	0.27	[-0.02, 0.01]
SD of the intercept (mean velocity)	Random (between-subject)	0.96				
Correlation between the intercept and mean velocity	Random (between-subject)	-0.73				
SD of the random slope of mean velocity	Random (between-subject)	2.25				
SD of the residual variability	Random (within-subjects)	0.69				

Group: HVL and LVL; HVL: high-velocity-loss threshold group; LVL: low-velocity-loss threshold group. Load = session loads (squat: low = 0.70 ms^{-1}, moderate = 0.60 ms^{-1}, and high =0.49 ms^{-1}; bench press: session loads (squat: low = 0.53 ms^{-1}, moderate = 0.45 ms^{-1}, and high =0.38 ms^{-1}). SD: Standard deviation.