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Perception of changes in bar velocity in resistance training: Accuracy levels within and between exercises

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ABSTRACT

Velocity-based training is a method used to monitor resistance-training programs based on repetition velocities measured with tracking devices. Since velocity measuring devices can be expensive and impractical, trainee's perception of changes in velocity (PCV) may be used as a possible substitute. Here, 20 resistance-trained males first completed 1 Repetition Maximum (RM) tests in the bench-press and squat. Then, in three counterbalanced sessions, participants completed four sets of eight repetitions in both exercises using 60%1RM (two-sessions) or 70%1RM. Starting from the second repetition, participants reported their PCV of each repetition as a percentage of the first repetition. Accuracy of PCV was calculated as the difference between PCV and actual changes in velocity measured with a linear-encoder. Three key findings emerged. First, the absolute error in the bench-press and squat was ≈5.8 percentage-points in the second repetition, and increased to 13.2 and 16.7 percentage-points, respectively, by the eighth repetition. Second, participants reduced the absolute error in the second 60%1RM session compared to the first by ≈1.7 in both exercises ($p \leq 0.007$). Third, participants were 4.2 times more likely to underestimate changes velocity in the squat compared to the bench-press. The gradual increments in the absolute error suggest that PCV may be better suited for sets of fewer repetitions (e.g., 4–5) and wider velocity-loss threshold ranges (e.g., 5–10%). The reduced absolute error in the second 60%1RM session suggests that PCV accuracy can be improved with practice. The systematic underestimation error in the squat suggests that a correction factor may increase PCV accuracy in this exercise.

1. Introduction

Velocity-based training (VBT) is a method used by strength and conditioning professionals to prescribe and monitor resistance training programs based on repetition velocities completed in different exercises [1–4]. VBT has a number of advantages. First, the progressive velocity loss across repetitions within sets provides a good indication of neuromuscular fatigue [5] and the number of repetitions one can complete before reaching task-failure [6]. Second, terminating sets at certain velocity loss thresholds (e.g., 10–30% relative to first repetition) using loads selected for specific training goals can lead to a range of positive neuromuscular adaptations [7–9]. VBT can thus optimize the training process by adjusting the number of repetitions completed per exercise in an individualized manner. However, to benefit from VBT, certain devices that measure velocity are required, such as inertial measurement units and linear position transducers (LPT) [10]. While the costs of such devices decreased in recent years, they are still not affordable to many. Moreover, using velocity measuring devices with large groups can be an impractical task. When velocity measuring devices are unavailable or impractical, a possible alternative can be the trainee's perception of velocity, or of changes in velocity, during ongoing sets. Assuming acceptable accuracy levels, applying VBT methodologies based on trainee's perception can be a useful and practical solution, due to its simplicity and cost-effectiveness.

To our knowledge, perception of velocity in resistance-training exercises was only examined in two studies by Bautista et al. [11,12]. In both studies, resistance-trained participants lifted loads ranging from 20% to 70% of 1RM in a blindfold manner for 2 to 4 repetitions, in the squat [12] and bench-press [11] exercises. Participants reported the perceived mean bar velocity at the completion of each set using a

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velocity scale ranging from 0.1 to 1.6 m/s^{-1}, that is accompanied by five qualitative descriptors (e.g., "very slow" and "power zone"). Actual bar velocity was concurrently measured using a LPT. In both studies, the authors reported minor differences between perceived and actual velocity (e.g., perceived (1.08 m/s) and actual (1.07 m/s) velocity) [14]. While the studies by Bautista et al. are an important step in the right direction, they include a number of limitations that warrant further investigations.

First, the relationship between perceived and actual velocity in Bautista's studies could be partly explained by the different loads on the bar which varied constantly and considerably between sets within the same session. Since velocity changes as a function of load, perception of heaviness in each set could have guided participants in their ratings, making the relationship stronger than if the load was constant. Second, participants reported the average velocity of each set that consisted of two to four repetitions. Since people tend to selectively remember the peak and the end of an event (i.e., peak-end rule [13,14]), it is of interest to examine velocity estimation of single repetitions, rather than sets. Third, Bautista's scale uses absolute velocity units (i.e., m/s^{-1}), which may be more difficult to grasp compared with other measurement units, such as percentages expressed relatively to a fixed anchor point. Fourth, a direct comparison in estimation accuracy between the bench-press and squat was not conducted in Bautista's studies. In view of the differences between the two exercises in range of motion, muscle mass, body position, and more, a direct comparison between them within the same study is of additional interest. Finally, there is a need to investigate not only the accuracy levels of perception of velocity, as Bautista's group has done, but also perception of changes in velocity (PCV). This is because PCV is more aligned with the practical utilization of VBT in which trainees are required to terminate a set once velocity has decreased to a set threshold relative to a baseline reference during the course of a set.

Accordingly, the purpose of the present study was to complement and expand upon Bautista's work. We investigated the accuracy of PCV among resistance-trained participants performing the barbell squat and bench-press exercises. Across three sessions, participants performed both exercises while lifting the same relative loads within a given session (60% or 70% of 1RM). Participants completed four sets of eight repetitions and reported their PCV after each repetition as a percent of the first repetition. In parallel to PCV, actual changes in bar velocity (ACV) were measured with a LPT for all repetitions and expressed as a percentage of actual velocity of the first repetition. In view of Bautista's work, we expected medium to strong estimation accuracies. However, given the differences between studies, our expectations were only tentative.

2. Materials and methods

2.1. Participants

Twenty male collegiate sport-science students volunteered to participate in the study (Table 1). To be included in the study participants had to be healthy, between the ages of 18 and 45, and have at least two years of resistance training experience in performing the squat and bench-press exercises. Finally, participants were required to lift 1.2 of their body mass in the 1RM test for both exercises. Written informed consent was obtained after the participants received an oral explanation of the purpose and potential risks of the study. All procedures were conducted in accordance with the Helsinki Declaration and approved by the Institution's Ethics Committee.

2.2. Procedure

A randomized cross-over design was used to investigate the relationship between PCV and ACV in bar velocity during the barbell squat and bench-press exercises performed in a Smith-Machine (Technogym Equipment, Barcelona, Spain). Participants reported to the laboratory for four sessions separated by three to six days. In the first session, participants completed a 1RM test in the barbell squat followed by the bench-press and were familiarized with the experimental procedures. In the three subsequent sessions, participants followed the exact same procedures, consisting of four sets of eight repetitions in the barbell squat followed by the bench press, with three minutes of rest between sets and exercises. In two of the experimental sessions, participants lifted 60% of 1RM in both exercises and in one session they lifted 70% of 1RM. These loads were selected as they fall within the recommended range for both hypertrophy and power development in the squat and bench-press exercises (30–70% of 1RM) [15,16]. However, we note this set and repetition configuration is more aligned with common hypertrophy guidelines [17]. After completing each repetition, participants verbally reported their PCV which was recorded via a tie-microphone attached to their shirts. During all sessions, no mirrors or any other reflective surface were present which could have assisted participants estimate changes in bar velocity.

Table 1
General demographics.

	Mean ± SD (Range)
Age	25.8 ± 2.4 (23–31)
Height (cm)	175 ± 6 (163–188)
Weight (kg)	79.7 ± 10 (65–100)
Experience in RT (yrs)	5.9 ± 3.7 (2–15)
Mean workouts per week	4.5 ± 0.5 (4–5)
1RM barbell bench-press (kg)	112.5 ± 18.5 (73–145)
1RM/ Bodyweight bench press	1.42 ± 0.2 (1–1.82)
Average velocity 1RM barbell bench press ($m \cdot s^{-1}$)	0.14 ± 0.04 (0.08–0.23)
1RM barbell squat (kg)	130.9 ± 21.3 (90–182)
1RM/ Bodyweight squat	1.64 ± 0.2 (1.2–2.1)
Average velocity 1RM barbell squat ($m \cdot s^{-1}$)	0.25 ± .06 (0.18–0.36)

[1]RM – one repetition maximum; RT – resistance training; SD – standard deviation.

2.3. 1RM tests and familiarization (Session 1)

Anthropometric measurements were taken and followed by an assessment of the required squat depth corresponding to a 90° knee angle measured with a hand-held goniometer. To ensure similar depth across sessions, a box with adjustable height was placed underneath the participants to which they were required to gently squat onto. Participants then performed a structured warm-up protocol consisting of dynamic stretching and calisthenics, followed by an individualized five-minutes warm-up. This warm-up protocol was identical in all sessions. Thereafter, participants were assessed in the barbell squat 1RM followed by the bench-press 1RM. The 1RM protocol consisted of consecutive lifts with progressively heavier loads until reaching the estimated or true 1RM. Two to three minutes of rest were provided between sets once the loads reached 90% of estimated 1RM. Bar velocity was recorded in all progressive 1RM attempts.

Following the 1RM tests, participants were familiarized with the procedure of the experimental sessions by performing two sets of 8–12 repetitions with an empty barbell in both exercises. Specifically, participants were asked to verbally report their PCV of the barbell starting from the second repetition and onward as a percent of the first repetition. That is, the first repetition was always considered 100% irrespective if the actual velocity resulted in the fastest repetition or not. Then, starting from the second repetition, participants reported percent values in relation to the first one. To illustrate, if any repetition starting from the second one is perceived to be as fast as the first one, then 100% is the value that should be reported. Alternately, if any repetition is perceived to be slower or faster by 5% relative to the first one, then 95% and 105% are the values that should be reported, respectively. Participants were asked to execute the concentric phase of each repetition as fast as possible. After each completed repetition, participants were asked to verbally state their PCV.

2.4. Experimental sessions (Sessions 2–4)

Following the standard warm-up, participants completed a progressive warm-up consisting of 10, 5, 3, 2 repetitions loaded with an empty bar, 40%, 50%, 60% of 1RM, respectively. In the 70% conditions, they completed two more reps with 70% of 1RM. The first warm-up set was used to practice the ratings of each repetition. Following two minutes of rest, participants completed four sets of eight repetitions with either 60% or 70% of 1RM. All sessions were performed at the same facilities, ran by the same two researchers at approximately the same time of the day (± 2 h). Participants were asked to refrain from intense training 24 h prior to testing days and to avoid muscular fatigue and soreness.

2.5. Bar velocity data collection

The mean propulsive velocity of bar movement during the concentric phase for each repetition in both exercises was examined. A LPT (Chronojump, Barcelona, Spain) sampling at 1000 Hz, fixed to the bar of the Smith machine at a perpendicular angle to the floor, and the commercial software provided by the manufacturer in conjunction with the device, were used to collect and compute the bar velocity outcomes. According to the software specifications, instantaneous velocity was smoothed with a fourth-order low-pass Butterworth filter, with a cut-off frequency of 10 Hz.

2.6. Statistical analysis

We descriptively inspected the individual data points using two approaches. First, we plotted the raw percentage point differences between the PCV and ACV. Second, we transformed all differences to absolute values (i.e., ignoring direction of error) which allowed us to quantify the extent of the average error while overcoming the offsetting effect of opposing negative and positive errors.

To inferentially analyze the absolute differences between PCV and ACV, we used the following model:

$$|PCV - ACV|_{it} = \beta_0 + \beta_{1-2}session_{it} + \beta_{3-5}set_{it} + \beta_6 repetition_{it} + \beta_7 exercise_{it} + \beta_k z_{it} + \alpha_i + \varepsilon_{it} \quad (1)$$

where absolute $error_{it}$ is the percentage point difference between PCV and ACV of subject i at repetition t; α_i is the subject specific deviation from the grand mean; and β_k represents all coefficients of three two-way interactions between exercise (squat = 1) on the one hand, and sessions, sets and repetitions on the other.

Turning to the direction of the error, we defined "underestimation of bar velocity" as observations in which participants' PCV was lower than the ACV (=1) and contrasted these to all other cases (PCV was equal to or higher than ACV = 0). We analyzed this outcome using a conditional fixed effects logistic regression as follows:

$$\ln\frac{p(U.E_{it}=1)}{p(U.E_{it}=0)} = \beta_{1-2}session_{it} + \beta_{3-5}set_{it} + \beta_6 repetition_{it} + \beta_7 exercise_{it} + \beta_g z_{it} + \varepsilon_{it} \quad (2)$$

Where $U.E_{it} = 1$ denotes subject i at repetition t underestimating bar velocity; and β_g represents all coefficients of the three two-way interactions between exercise on the one hand, and sessions, sets and repetitions on the other. Note that β_0 and α_i have been "conditioned out" of the likelihood function. In addition, to ease interpretation of the results and enable a simple comparison between all analyzed categories in probability of underestimation, rather than odds ratios relative to the reference category, we calculated average predicted probabilities by exercise and across sessions, sets and repetitions by using an unconditional fixed effects logistic regression (since the average number of repetitions per subject is 166.2, the incidental parameters problem is negligible).

3. Results

3.1. Descriptive statistics

Figs. 1 and 2 depict the raw and absolute individual data points, respectively, across sessions, exercises and repetitions. We observed two main patterns in Fig. 1. First, variance increased across repetitions in both exercises. Second, in the bench-press the mean remained relatively close to zero whereas in the squat it was consistently under the zero line, and the extent of this underestimation error grew as a function of the repetitions. In Fig. 2, the increase in variance across repetitions is similar to that illustrated in Fig. 1. However, the mean absolute error increased in a similar fashion in both exercises.

3.2. Extent of error

In this section we focus on the key results and direct the interested reader to explore all other effects fully presented in Table 2 and visible in Fig. 3. When controlling for sessions, sets, repetitions and participants, the absolute error was 1.69 percentage points higher in the squat than in the bench-press ($p < 0.001$). In both exercises, the absolute error was lower in the second 60%1RM session compared to the first session, with significant reductions of 2.2 and 1.2 percentage points in the squat and bench-press, respectively ($p \leq 0.007$). In both exercises, the absolute error in the 70%1RM was mostly similar to the first 60%1RM session ($p \geq 0.311$, $-0.31 < b < 0.45$), but significantly higher than the second 60%1RM session ($p < 0.001$, $b \approx 1.7$). We observed no meaningful differences in these effects between the exercises ($p < 0.117$, $-1 < b < -0.8$ percentage points).

In the bench-press, the absolute error in the third and fourth sets was higher than the first set ($p \leq 0.013$, $b \approx 1.3$). In contrast, in the squat, differences between the sets were trivial ($p \geq 0.187$, $-0.67 < b < 0.3$ percentage points). Yet, excluding the effect of set 3 ($p = 0.002$, $b = 2.2$), differences between the exercises in the effects of sets were negligible.

In both exercises the absolute error increased with every successive repetition. The increment in the error related with each completed repetition was significantly higher in the squat ($p < 0.001$, $b = 1.8$) compared to the bench-press ($p < 0.001$, $b = 1.2$). Therefore, while the error in both exercises in the second repetition is estimated at ~5.85 percentage-points, by the eighth repetition it increased to 13.2 in the bench-press and to 16.7 percentage-points in the squat.

3.3. Direction of error

All effects are presented in Table 3 and visible in Fig. 4. The odds of underestimating ACV, controlling for sessions, sets, repetitions and participants were 4.24 times higher in the squat exercise compared with the bench-press ($p < 0.001$). In the bench-press, the odds of underestimating ACV decreased as sessions and sets progressed ($p < 0.001$). In contrast, we detected no effect of session or set in the squat ($p \geq 0.397$, $0.85 < OR < 1.01$). Therefore, the decrease in the odds of underestimating ACV were larger in the bench-press when compared with the squat in session 3 ($p = 0.012$, $OR = 1.7$) and, likewise, in sets 3 and 4 ($p < 0.001$, $OR = 2.31$ and 2.64, respectively). The odds of underestimating ACV in the squat increased, on average, with each repetition by 17% ($p < 0.001$). In contrast, they decreased, on average, by 30% with each repetition in the bench-press ($p < 0.001$). The effect of repetition significantly differed between the exercises ($p < 0.001$).

Comparing the predicted probabilities of underestimating ACV (using unconditional maximum likelihood model), we note that in the squat the probability of underestimating ACV remained almost constant

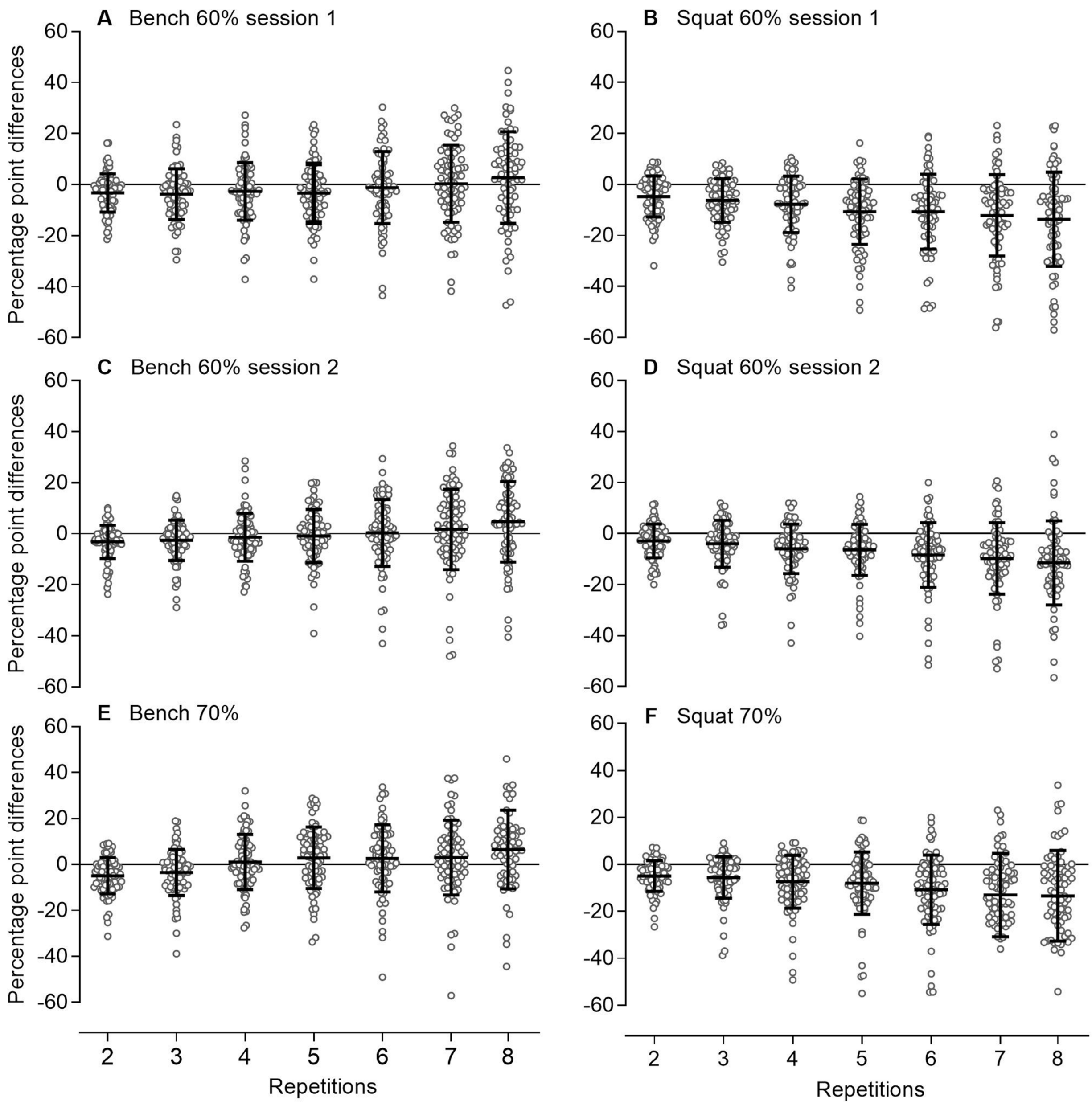

Fig. 1. Data points of the percentage-point differences between PCV and ACV across sessions and repetitions. The mid-horizontal line and error bars represent means and SDs.

at ~80% throughout sessions and sets and grew from 71% to 83% as repetitions progressed. In contrast, in the bench-press, the probability of underestimating ACV decreased from 71% in repetition 2 to 35% in repetition 8 and from ~60% in the first session or set to as low as ~47.5% in the last session or set.

4. Discussion

The purpose of this study was to examine the accuracy of PCV among resistance-trained participants performing the barbell squat and bench-press across loads, sets and repetitions. We observed three main findings. First, in both exercises, the absolute error rates increased with consecutive repetitions, and the growth in error was larger in the squat, compared to the bench. Second, participants improved their accuracy ratings in the second 60%1RM session. Third, looking at the error's direction, participants systematically underestimated ACV in the squat across all repetitions.

Across exercises a similar pattern emerged, in which the absolute error increased with consecutive repetitions. Specifically, the absolute error increased by 1.2 percentage points in the bench-press and by 1.8 in the squat. These errors can be explained by a number of reasons. The lack of calibration against the actual velocity of repetitions may have hindered participant's accuracy levels. We assume that informing participants about the extent of their error in real time can improve estimation accuracy [18]. This assumption is supported by the fact that participants improved estimation accuracy from the first to the second

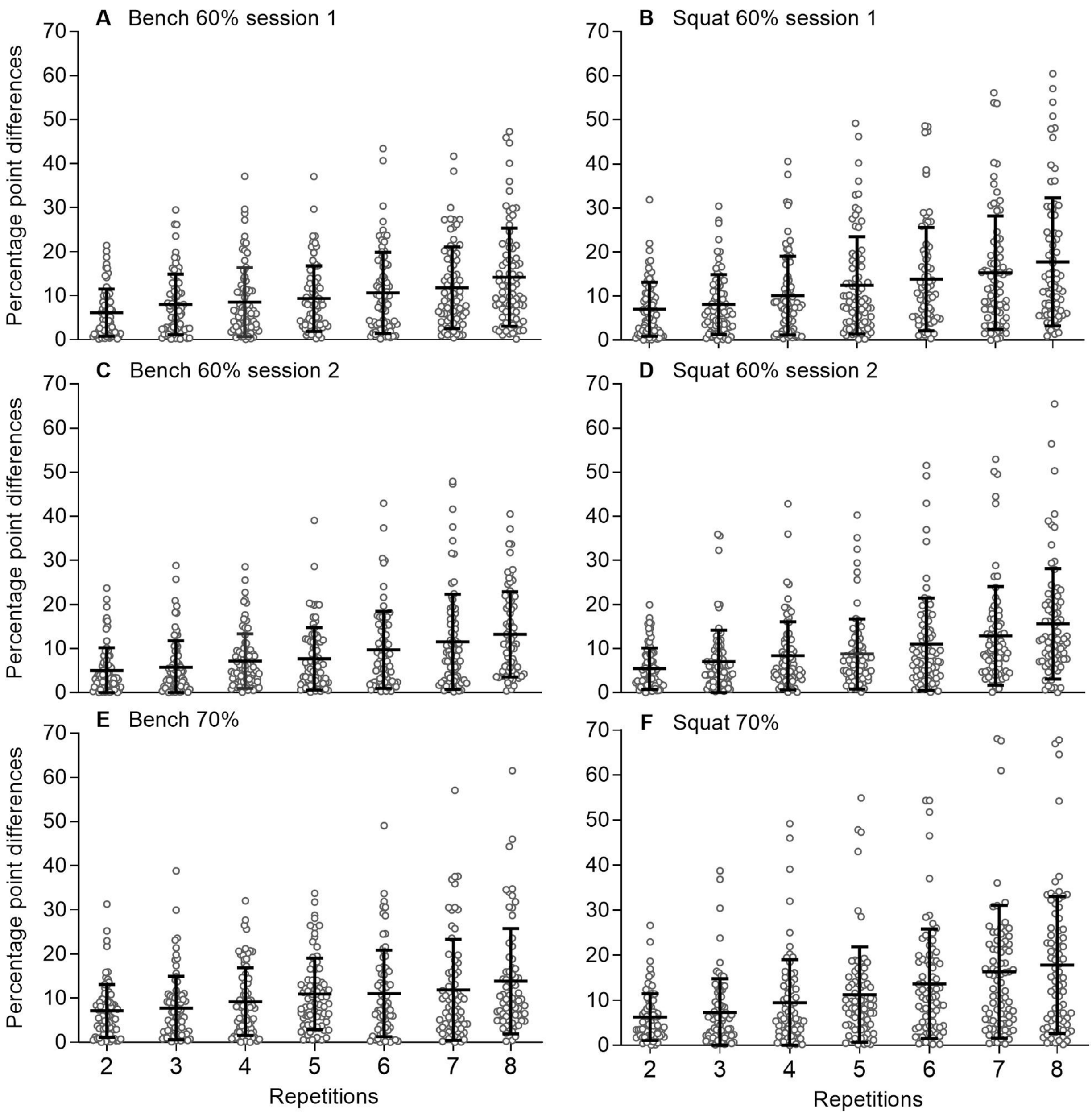

Fig. 2. Data points of absolute value percentage-point differences between PCV and ACV across sessions and repetitions. The mid-horizontal line and error bars represent means and SDs.

60%1RM session in both exercises, despite not receiving any information about ACV. Since all ratings were based on participant's PCV of the first repetition, miscalculating the velocity of this anchor could have profoundly impacted the remaining ratings during the ongoing set. The time elapsed between the first and subsequent repetitions, could have hindered PCV accuracy. This observation is analogues to studies reporting lower accuracies of participants' estimation of how many additional repetitions they think they can complete before reaching task failure, the further they are from task failure (i.e., lower accuracy in beginning compared to the midway or end of a set) [19,20]. Whereas in these studies the anchor was the final repetition, in the present study the anchor was the first repetition. Nevertheless, in both cases the further one is from the anchor, the lower accuracy becomes.

The neuromuscular fatigue that had likely accumulated as repetitions progressed may have interfered with the ability to accurately estimate PCV [21,22]. For example, it is possible that the buildup of metabolic byproducts increased the discharge frequency of group III and IV afferents to the central nervous system [23,24], which led to lower PCV accuracy in . Increases in neuromuscular fatigue are also associated with increases in perception of discomfort [25] and negative affect [26]. Such perceptions could have could distracted participants from their goal of estimating change in velocity, leading to greater inaccuracies. Future studies should collect other perceptions, such as discomfort, effort, fatigue, and negative affect, alongside PCV, and investigate the relationship between them. As a whole, these findings are inconsistent with Bautista work [11,12], in which relatively accurate

Table 2
Fixed effects (within-subjects) linear regression of extent of error in velocity.

	Coefficient	S.E
Constant	5.307***	1.562
[Session 60%-1]		
Session 60%-2	−1.196**	0.442
Session 70%	0.45	0.446
[Set 1]		
Set 2	0.545	0.509
Set 3	1.616**	0.51
Set 4	1.064*	0.516
Repetitions	1.217***	0.0909
[Bench-press]		
Squat	1.544*	0.733
Session 60%-2*Squat	−0.981	0.625
Session 70%*Squat	−0.765	0.628
Set 2*Squat	−1.216	0.719
Set 3*Squat	−2.198**	0.72
Set 4*Squat	−0.759	0.726
Repetitions*Squat	0.594***	0.128
N (within 20 subjects)	3,324	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

velocity estimation values were observed. These differences likely stem from the large differences in designs and measurement strategies which preclude a direct comparison.

The larger absolute errors observed in the squat compared to the bench-press (1.7 percentage-points difference), can result from a number of differences between the exercises. The mean distance the barbell travelled was 0.35 m in the bench-press and 0.55 m in the squat. The bench-press is also characterized by a greater propulsive portion of the bar compared to the squat [27,28]. The shorter distances the barbell travels in the bench-press, coupled with its longer propulsive phase, may have facilitated a more accurate perception of its velocity. Then, in contrast to the squat, during the bench-press participants were able to visually observe parts of the moving bar which may have assisted in gauging its velocity. The amount and size of muscle mass involved in the squat exercise is greater than the bench-press. Finally, upper body muscles are used more frequently than the lower body muscles during daily activities [29], and are commonly involved in fine motor tasks requiring movement accuracy, such as grasping and reaching. This fact can also explain why movement velocity with the upper body is estimated with greater precision. Future studies are required to directly examine the posed explanations to the differences between the body parts.

In contrast to the absolute error, a divergent pattern emerged between the exercises when inspecting the directional error. Large and systematic underestimation of ACV errors occurred in the squat. Conversely, a smaller shift from over- to underestimation of ACV error occurred in the bench-press. Collectively, participants were 4.2 times more likely to underestimate ACV in the squat compared with the bench-press. While some of the speculative reasons mentioned previously concerning the differences between exercises in absolute error may also hold true for the directional error, we are uncertain why such large differences between exercises occurred. Specifically, we are uncertain what can cause the systematic underestimation in the squat. Practically, if using perception of bar velocity to reach a velocity threshold in the squat, it may be reasonable to use a correction factor to

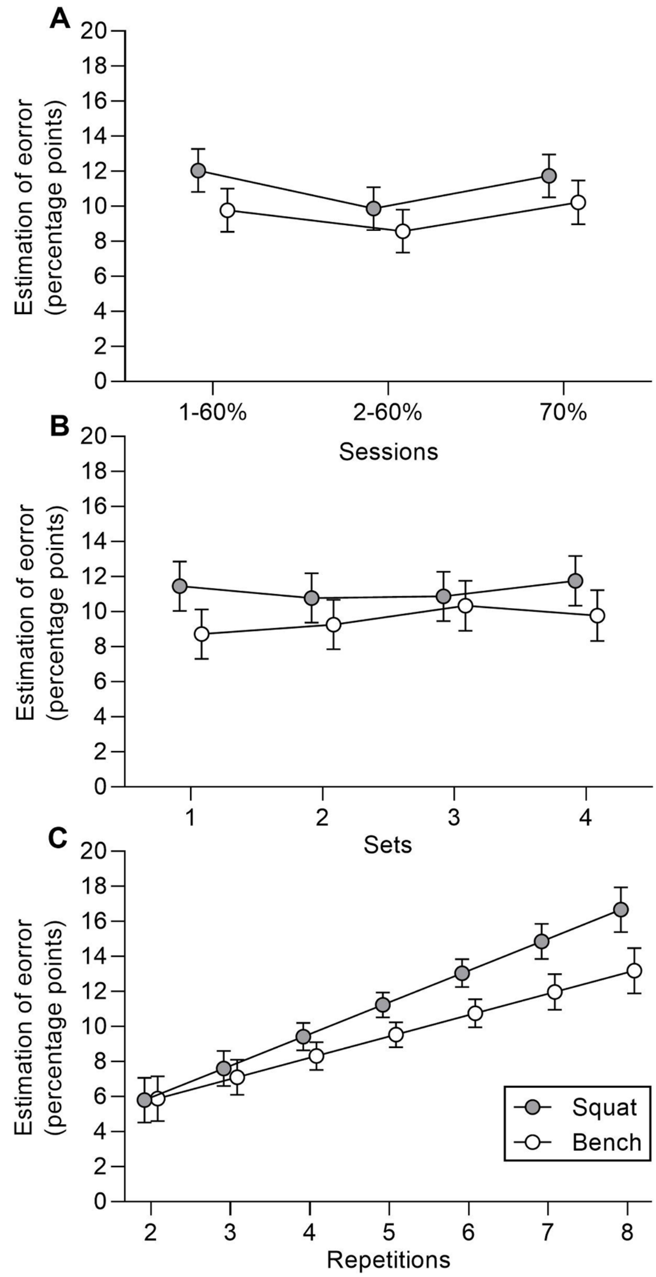

Fig. 3. The graphs present estimations of error (|PCV-ACV|) across exercise and sessions (A), sets (B), or repetitions (C) when all other variables are set to their mean. Circles and error bars represent estimations and 95% confidence intervals.

overcome the systematic bias.

This study has a number of strengths and limitations worthy of discussion. In total, more than 3300 repetitions were collected and analyzed, adding considerable statistical power to this study. While participants in this study were experienced in resistance-training, they were not experienced in VBT, and were not presented with actual bar velocity throughout the study. Both factors could have considerably

Table 3
Conditional fixed-effects logistic regression of odds of underestimating bar velocity.

	Odds ratio	S.E.
[Session 60%-1]		
Session 60%-2	0.731*	0.108
Session 70%	0.555***	0.0827
[Set 1]		
Set 2	0.680*	0.116
Set 3	0.370***	0.0635
Set 4	0.385***	0.0668
Repetitions	0.703***	0.0223
[Bench-press]		
Squat	0.431**	0.113
Session 60%-2*Squat	1.266	0.279
Session 70%*Squat	1.713*	0.38
Set 2*Squat	1.321	0.336
Set 3*Squat	2.304**	0.587
Set 4*Squat	2.634***	0.682
Repetitions*Squat	1.672***	0.078
N (within 20 subjects)	3,324	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

influenced the results of this study. Future studies are required to examine if perception of velocity is more accurate among those experienced with VBT, and studies that include ACV information to examine if, and to what extent, estimation accuracy can be improved. Indeed, it is possible that with some practice, estimation accuracy can considerably improve. Moreover, future studies should examine PCV in sets when participants are instructed to reach task failure. Such studies would provide an answer to whether PCV during ongoing sets can predict the point in which one reaches task failure (for a related example, see Gentil et al. [30]). They would also be able to examine PCV accuracy levels throughout the entire range of actual change in bar velocity (e.g., 20% or 30% of first repetition), rather than look at the effect of repetition given a fixed and relatively low number of repetitions. Finally, developing a richer understanding of the underlining mechanisms causing differences between upper and lower body exercises is warranted.

5. Practical application

Whether PCV should be used in practice, depends on the velocity-loss threshold for set termination, the precision one is after, and the number of repetitions expected to be completed per set. For example, PCV may be used in sessions composed of low velocity-loss threshold per set (e.g., 5–10% of initial velocity), fewer expected repetitions per set (e.g., 4–6) and willingness to accept wider error rates (e.g., ~10%). In contrast, a session composed of high velocity-loss threshold (e.g., 10–30% of initial velocity), higher expected repetitions per set (e.g., 10–20), in which greater precision is sought after (e.g., < 3%), would deem this strategy unacceptable. In such training sessions, velocity measuring devices would have to be used. Note that the reduced error rates observed in the second 60%1RM session in both exercises suggests that accuracy rates can improve with practice. Finally, since participants underestimated PCV in the squat, a correction factor may improve accuracy in this exercise. For example, if the goal is a velocity loss of 10% per set and the expected underestimation is 5%, then requiring one to terminate a set once the perceived velocity loss corresponds to 15% may lead to a more accurate result.

6. Conclusion

To our knowledge, this is the first study to investigate the accuracy levels of perception of changes in velocity as a percent of the first repetition in the squat and bench-press, across loads, sets, and repetitions. We observed that the absolute error increased with subsequent

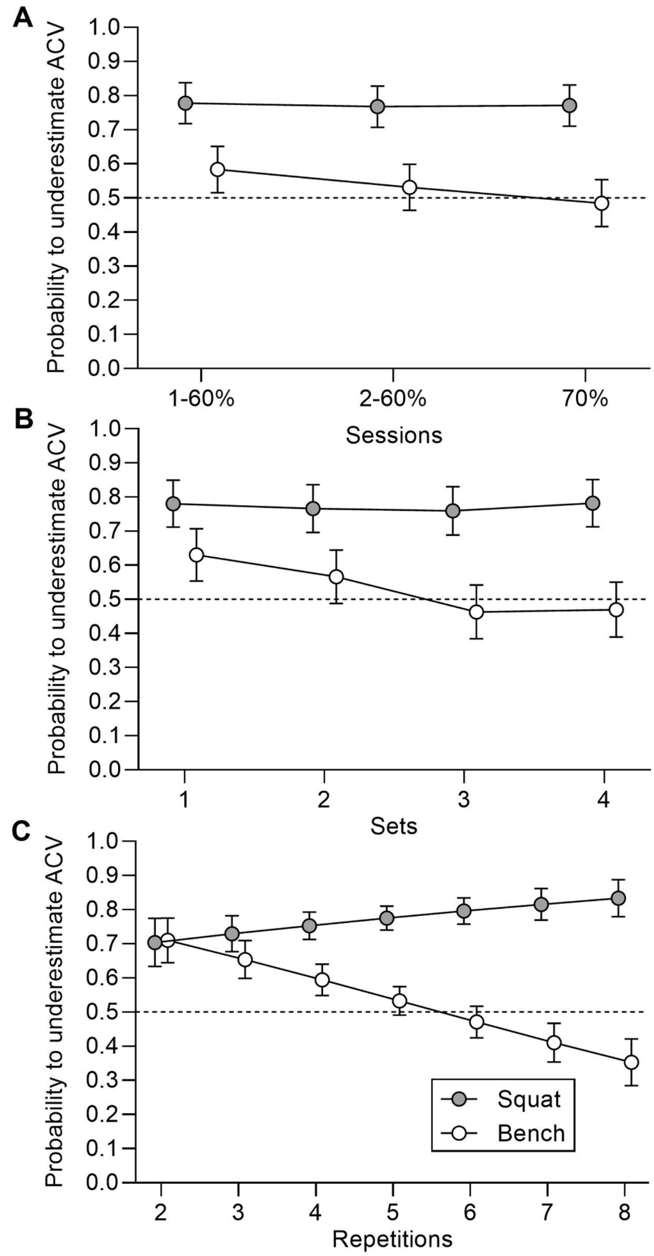

Fig. 4. The graphs present average predicted probability of underestimating ACV across exercise and sessions (A), sets (B), or repetitions (C). The circles and error bars represent the probability and 95% confidence intervals. The dashed horizontal lines represent an equal probability to underestimate as to overestimate ACV.

repetitions in both exercises, with larger errors in the squat. Participants improved their accuracy ratings between the first and second 60%1RM session across exercises. A systematic bias was observed in the squat, in which participants underestimated actual bar velocity. No meaningful effect of sets and load occurred. Given the potential of this approach, more research is currently required to examine the estimation accuracy levels of different populations and the extent of possible improvements in estimation accuracy.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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