Perception of barbell velocity: Can individuals accurately perceive changes in velocity?

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ABSTRACT

The aim of the study was to investigate whether resistance-trained participants can accurately predict changes in barbell velocity, specifically in the deadlift exercise, without feedback from velocity based training (VBT) devices. Seventeen participants (16 male, 1 female; age = 24.7 ± 3.8) were randomized in a counterbalanced, crossover design two experimental sessions that consisted of three sets of Deadlift at 60-and-80% one-repetition maximum (1RM). The number of repetitions were determined by the participants as they were asked to terminate each set when they felt the barbell velocity had reduced by 20%, relative to repetition one. A binomial mixed effects regression model was used to assess the accuracy of participants ability to stop after reaching at least 20% velocity loss. Participants tended to underestimate their proximity to 20% velocity loss and thus had relatively low probability of correctly stopping after reaching this threshold. There was only a 10.49% probability that people could perceive at least 20% velocity loss greater than chance (i.e., 50% probability). Our data, suggests that most participants cannot accurately perceive changes in velocity without exposure to augmented feedback.

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Introduction

Velocity based training (VBT) is a flexible training method based on the strong inverse relationship between load (kg) and movement velocity (m.s^{-1}) (Weakley et al., 2021). VBT can be utilised in several ways to inform and support training practices; test and monitor individuals via load-velocity profiling (Thompson et al., 2021), autoregulate load prescriptions via velocity zones and targets (Dorrell et al., 2020), motivate athletes by driving intent (Weakley, Wilson, et al., 2020) and regulate both effort and volume via velocity loss thresholds (Weakley, Ramirez-Lopez, et al., 2020). Progressive velocity loss thresholds is theorised as an indicative marker of neuromuscular fatigue (Sánchez-Medina & González-Badillo, 2011), demonstrating its usefulness when monitoring effort in resistance exercise. Whilst the evidence supporting the benefits for velocity-based training compared to traditional training approaches is currently unclear (Orange et al., 2022), the consistent acute responses of velocity measures to resistance training bouts make them an appealing approach to monitoring and manipulation of training. Strength and conditioning professionals can therefore measure velocity routinely to adjust training loads within session without the need for maximal testing (i.e. determination of one repetition maximum), allowing more pragmatic individualization of training programmes (Sindiani et al., 2020). Several devices are now commercially available that facilitate the measurement of barbell velocity utilising valid and reliable technologies such as inertial measurement units, linear position/velocity transducers, and smartphone applications (Balsalobre-Fernández et al., 2016; Martínez-Cava et al., 2020; Thompson et al., 2020; van den Tillaar & Ball, 2020). However, some devices are still impractical outside of laboratory settings and difficult to use in larger group settings (Sindiani et al., 2020). Furthermore, whilst devices are becoming cheaper, price is still a considerable barrier of entry for many users, for example those training athletes in groups (Romagnoli & Piacentini, 2022).

Perception of velocity, i.e., participants subjectively estimate movement velocity, has recently been proposed as an alternative to direct measurement of barbell velocity (Lazarus et al., 2021; Sindiani et al., 2020), meaning individuals would not need to invest in measurement devices. A paucity of literature exists examining the perception of barbell velocity during resistance exercise. Bautista et al. (2014)

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developed a subjective rating scale of absolute velocity (i.e., in $m \cdot s^{-1}$ units) perception during the bench press at various loads ranging from <40% 1RM to <70% 1RM. Whilst the authors reported concurrent validity of the scale, participants were provided with velocity feedback during familiarisation, potentially influencing their interpretation of the motor skill during the experimental trials. It can therefore be argued that prior feedback as well as knowledge of the load-velocity relationship might have influenced the authors findings. Further criticisms suggest that the perception of a single repetitions absolute velocity is limited in its application (Sindiani et al. 2020). Perception of relative changes in velocity (i.e., absolute velocity [% units] or change in velocity between reps [Δ% units] expressed relative to the first repetition) might be more practically relevant as prescriptive strategies such as velocity loss are easier to administer (Banyard et al., 2017; Weakley et al., 2021). Previous research has examined changes in neuromuscular performance and muscle morphology when using different percentage reductions in velocity loss, for example 20% versus 40% (Gantois et al., 2021). As different velocity loss thresholds may result in different adaptations, perception of velocity change could be of more importance to practitioners than estimating the velocity of a single repetition.

Further studies have now extended on the original work of Bautista et al. (2014) and asked participants to report perceived velocity at each repetition relative to the first repetition in a range of exercises and populations (Lazarus et al., 2021; Sindiani et al., 2020). Both investigations required participants to verbally report perceived velocity as a percentage change relative to the first repetition. Although this work is a step in the right direction towards understanding how subjective estimation of velocity can be practically applied, we argue that asking participants to continually report velocity changes has limited practical applications for strength and conditioning coaches and the athletes themselves. Further, the aim of velocity loss-based training is to have participants cease exercise once a certain threshold has been achieved, and preferably not to overshoot too many repetitions. As such, it is of interest to explore behaviourally the accuracy of participants in their ability to perceive a specific threshold Δ% of velocity and to stop exercise at that point. Therefore, in the present study we explored the ability of participants to just stop at when they perceived a 20% threshold has been met.

Methods

Participants

A convenience sample of seventeen participants (16 male, 1 female) agreed to participate in the study (table 1). For transparency we report the sample size justification as being due to the resource constraints of this study being part of student research projects (Lakens, 2021). Participants were required to be over the age of 18, injury-free, and at least 1 year of experience with resistance training and performing the deadlift exercise. Informed consent was provided by all participants and all procedures were in accordance with the Helsinki Declaration, the institutions' ethical procedures as well as the Norwegian centre for research data (NSD).

Table 1. Participant information

	Mean ± SD
Age (years)	24.7 ± 3.8
Height (cm)	177.3 ± 6.8
Mass (kg)	78.8 ± 8.4
Deadlift 1RM (kg)	167.5 ± 23.3
Deadlift 1RM / bodyweight	2.1 ± 0.2
Deadlift 1RM mean concentric velocity (m/s)	0.16 ± 0.04

Procedures

A cross-sectional investigation was conducted to examine perception of velocity changes in two different loads of the deadlift exercise (60% and 80% 1RM). The study was not pre-registered and was explicitly exploratory. We opted to explore two loads commonly used in velocity loss-based resistance training and had participants also perform multiple sets increasing the number of observations per participant to improve precision of parameter estimates. Although two loading conditions were employed, we were primarily interested in the main intercept for our models (i.e., accuracy of perception in general) and thus treated these as random factors (see analysis below) with the aim of enhancing generalisability of possible inductive inferences from this exploratory study (Yarkoni, 2020). Participants were randomized in a counterbalanced, crossover design completing three testing sessions that were separated 2 – 3 days apart. Participants first completed a 1RM determination session that included familiarization with the experimental sessions. In the two experimental sessions, participants performed three sets of the deadlift exercise. The number of repetitions were not specified to the participants and instead they were told to terminate the set when they believe the velocity had dropped by 20% from repetition one. Based on the randomisation, participants would start session one with either 60%1RM or 80%1RM and then the other load in session two.

1RM determination and familiarisation

Participants underwent a 5 – 10 minutes individualized warm up that consisted of rowing and self-selected dynamic stretching. This was followed by performing the deadlift with a 20kg barbell (Eleiko, Halmstad, Sweden) using incremental loads based on percentages of an estimated 1RM (Raastad et al., 2010). Following completion of a single repetition at 90% of estimated 1RM, participants were given 3 – 5 minutes of rest between 1RM attempts. In the same manner as Sindiani et al. (2020), mean concentric velocity for all 1RM attempts were recorded. For familiarisation of the experimental testing sessions, participants performed several warm-up sets with a metronome that provided 5 second intervals between repetitions. Participants were instructed to begin a repetition on a beep and ensure the full repetition was performed before the following beep. Participants were required to perform the deadlift using the conventional style (McGuigan & Wilson, 1996) and could adopt either a mixed or olympic grip. All participants were shod and were allowed to wear a lifting belt if they wished, but were required to wear this for all testing sessions. All weight plates (Kraftmark, Västerås, Sweden) were verified using a force plate (Ergotest innovation AS, Porsgrunn, Norway).

Experimental sessions

Participants completed the same individualised warm-up to the first visit followed by a progressive warm-up with the deadlift exercise consisting of 8, 5, and 3 repetitions with 40%, 50% and 70% 1RM, respectively. Following 3 – 5 minutes of rest, participants completed the first set of three experimental sets of the deadlift with either 60% or 80% 1RM. A metronome started and participants were free to begin when they wanted but once they began, they must have completed both the concentric and eccentric phase of deadlift before then subsequent beep. This meant

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there were 5 seconds between the start of each repetition. Participants were instructed to lift the barbell as fast as possible and to terminate the set once they believed their velocity had dropped by 20% relative to the first repetition. Participants performed 3 sets with 3 minutes rest between.

Mean concentric barbell velocity was measured using a linear encoder (ML6ENC02, Ergotest innovation AS, Porsgrunn, Norway), sampling at 200hz running and synchronized with Musclelab (v10, ErgotestTechnology AS, Langesund, Norway). The linear encoder was placed under the center of the barbell with the string 90° relative to the floor. Mean concentric velocity was defined as the average velocity between minimum and maximum barbell displacement and was calculated as per the manufacturer's guidelines.

Statistical Analyses

As noted, this study was treated as exploratory. Thus, analysis of the dataset generated from our participants was performed such that inferential statistics were treated as highly unstable local descriptions of the relations between model assumptions and data in order to acknowledge the inherent uncertainty in drawing generalised inferences from single and small samples (Amrhein, Trafimow, et al., 2019). For all analyses we opted to avoid dichotomising the existence of effects and therefore did not employ traditional null hypothesis significance testing, which has been extensively critiqued (Amrhein, Greenland, et al., 2019; McShane et al., 2019). Instead, we opted to take an estimation-based approach instead (Cumming, 2014; Gardner & Altman, 1986), based within a Bayesian framework (Kruschke & Liddell, 2018) which has been suggested as a worthwhile approach in sport science where samples and effects are often both small (Mengersen et al., 2016). For all analyses effect estimates and their precision, along with conclusions based upon them, were interpreted continuously and probabilistically, considering data quality, plausibility of effect, and previous literature, all within the context of each outcome (Amrhein, Trafimow, et al., 2019; McShane et al., 2019).

All analysis was conducted in R (v 4.0.2; R Core Team, https://www.r-project.org/) and all data and code utilised is presented in the supplementary materials (https://osf.io/z2h3f/). Bayesian regression models described below were all fit using the ‘brms’ package (Bürkner, 2017, 2018) with posterior draws taken using ‘tidybayes’ (Kay, 2021) and ‘emmeans’ (Lenth et al., 2021). Given the novel study design we did not have a clear intuition or informed opinion about what prior to set and so opted to use the default priors in brms. All data visualisations were made using ‘ggplot2’ (Wickham, 2016) and ‘patchwork’ (Pedersen, 2020). Within the visualisations and text we note the model specification in Pinheiro-Bates-modified Wilkinson-Rogers notation (Pinheiro & Bates, 2000; Wilkinson & Rogers, 1973) for brevity.

We utilized a two part ‘hurdle’ model for our analysis. First, we explored the accuracy of participants ability to stop after reaching at least 20% velocity loss using a binomial mixed effects regression model. Correct responses (i.e., where participants correctly stopped after reaching at least 20% velocity loss) were coded as 1 and the following model was fit,

Response ~ 1 + (1|Set) + (1|Load) + (1|id)

For this main model we used four Monte Carlo Markov Chains with 1000 warmup and 1000 sampling iterations. Draws were then taken from the posterior distribution (n=4000) for the model intercept term. For the second part, we employed a poisson mixed effects regression model to then explore how many additional repetitions were performed after participants achieved at least 20% velocity loss and thus how far they ‘overshot’ (note, in this model a repetition number of zero meant they accurately stopped immediately after reaching at least 20% velocity loss). The following model was fit,

Number of Repetitions ~ 1 + (1|Set) + (1|Load) + (1|id)

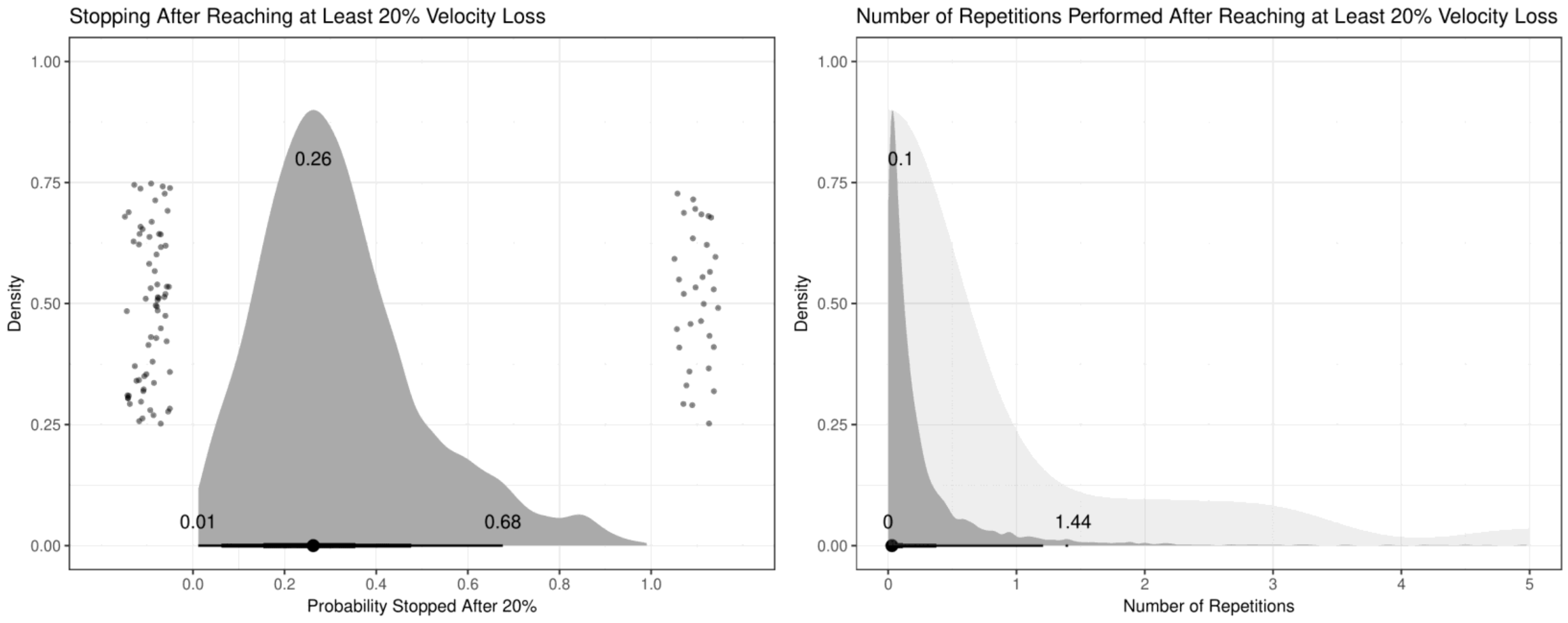
Again, we used four Monte Carlo Markov Chains with 1000 warmup and 1000 sampling iterations and draws were then taken from the posterior distribution (n=4000) for the model intercept term. We calculated the mode and the 95% highest density interval (HDI) from the posterior probability density functions for each group effect estimate. These gave us the most probable value of the parameter, in addition to the range over which there was a 95% probability that the parameter lay within. Model summary tables were produced for both binomial and poisson models and posterior probability distributions, modes and 95% HDIs, as well as raw data, were produced graphically.

Results

Both model summary tables are available in the online supplementary materials (https://osf.io/kqyjp/). Graphical display of the model outputs is shown in figure 1.

The binomial model suggested that participants tended to underestimate their proximity to 20% velocity loss and thus had relatively low probability of correctly stopping after reaching this threshold. The modal probability of correctly stopping after 20% velocity was 26%; however, the precision of our estimate was relatively wide with 95% HDIs ranging from 0.1% to 68%. In fact, considering the posterior probability distribution, there was only a 10.49% probability that people could perceive at least 20% velocity loss greater than chance (i.e., 50% probability).

The poisson model, because of the general under prediction found in the binomial model, had few observations to fit (i.e., few overcame the initial hurdle of correctly perceiving they had reached at least 20% velocity loss). As a result, it did not appear particularly well fit to the underlying data (see figure 1, right panel). Thus, the results of this should be treated with caution. However, it did appear that there was a relatively low probability that those who did correctly perceive 20% velocity loss would overshoot considerably in terms of the number of repetitions performed over that needed. The modal number of repetitions was only 0.1 with 95% HDIs ranging from 0 to 1.44 repetitions. Considering the posterior probability distribution there was a 96.95% probability that people performed no more than one repetition more than was needed. Considering the probability density function for the raw data, this was 84.38%. Thus, despite the poor model fit visually, both the model and raw data suggested that there was a low probability that those who correctly perceived 20% velocity loss overshot drastically in the number of repetitions performed.



Stopping After Reaching at Least 20% Velocity Loss

Number of Repetitions Performed After Reaching at Least 20% Velocity Loss

Posterior probability distributions (values are mode and 95% highest density intervals)
Hurdle model employed
(A) Binomial Model: Stopped After 20% ~ 1 + (1|Set) + (1|Load) + (1|id)
(B) Poisson Model: Number of Repetitions After 20% ~ 1 + (1|Set) + (1|Load) + (1|id)
Note, points in left panel are raw responses, and the light grey distribution in the right panel is for raw repetition numbers

Figure 1. Posterior probability distributions for the binomial model (left panel), and poisson model (right panel). Modal estimates and 95% highest density intervals are shown as are raw data.

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4.0 Discussion

The aim of the investigation was to examine perception of velocity changes in the conventional deadlift exercise. Specifically, the accuracy of participants' ability to perceive a specific threshold Δ% of velocity and to stop exercise at that point. When participants were asked to terminate their set when they believed their barbell velocity had reduced by 20%, relative to the first repetition, our findings demonstrate that participants tended to underestimate their velocity loss. There was only a 10.5% probability that participants could accurately perceive at least 20% velocity loss had occurred in their set.

Perhaps the fundamental difference in this study compared with prior investigations is that participants were not provided with any feedback on velocity at any point. To develop their perception of velocity scale, Bautista et al. (2014) provided participants with the minimum and maximum velocities achieved at different percentages of 1RM in the bench press during familiarization. Following on from the original study, Bautista et al. (2016) used their perception of velocity scale within a back squat familiarization session which led to positive linear correlations between perceived velocity and actual velocity ($r = .978$). The authors acknowledge their findings may in part be due to memory-anchoring procedures (Lagally & Costigan, 2004) whereby participants were provided with knowledge of movement velocities allowing a scale to be anchored through definition (Noble & Robertson, 1996) e.g. "very fast". Furthermore, Lazarus et al., (2021) were able to reduce accuracy error by 2.3 percentage points by providing a single session of verbal and visual feedback on the extent of the participants errors. By not providing any feedback on velocity, our participants were not able to engage in any memory-anchoring process, which may explain their lack of accuracy compared to previous literature. Similarly to this study, Sindiani et al. (2020) did not provide velocity data to their participants, and the authors argued this lack of augmented feedback may have led to participants being 4.2 times more likely to underestimate velocity. Whilst the existing literature (Bautista et al., 2016; Lazarus et al., 2021; Romagnoli & Piacentini, 2022) tends to support the use of augmented feedback via devices in increasing accuracy of velocity estimation, the aim of this investigation was to examine the feasibility of eliminating devices used for measuring velocity by exploring a pragmatic behavioural approach to perception of velocity loss.

Velocity loss thresholds are becoming increasingly popular within S&C as a more sensitive and robust method for prescribing volume and regulating neuromuscular fatigue than traditional sets and reps (Pareja-Blanco et al., 2020). Research suggests that inter-individual variability in rep-load capabilities is evident, particularly when comparing athletes from different sports (e.g., weightlifter vs. endurance athlete) (Richens & Cleather, 2014). Velocity loss, however, enables coaches to prescribe volume based off desired physiological adaptations (e.g., 40% for hypertrophy) (Pareja-Blanco et al., 2017) and reduce sub-optimal stimuli because of this variability. Velocity loss is simple to administer as it requires no prior analysis such as load-velocity profiling and has a direct link to a neuromuscular mechanical variable, velocity. Despite velocity loss still requiring technology, and the perception of velocity loss being inconclusive, practitioners should seek to prescribe volume this way where possible to optimize programming.

To our knowledge, this the first investigation that has asked participants to estimate a specific velocity loss and to terminate a set based on this i.e. the participants were required to perceive a velocity loss threshold that has typically been utilized in previous VBT investigations (Banyard et al., 2017; Gantois et al., 2021). We therefore argue that this is a more practical and ecologically valid investigation when assessing the efficacy of using velocity to regulate resistance training without the assistance of velocity measuring devices. Nevertheless, our data, in combination with other studies, suggests that most participants cannot accurately perceive changes in velocity without exposure to augmented feedback. Yet, for those participants that did accurately perceive the velocity loss threshold there was little absolute error (i.e., they did not perform many more additional repetitions than required). Thus, a fruitful avenue for future research might be to explore factors that either improve accuracy of perception of velocity or determine what individual characteristics are associated with accuracy to enable coaches to determine which athletes might best utilize this approach.

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Data and Supplementary Material Accessibility

All materials, data, and code are available on the Open Science Framework project page for this study https://osf.io/8vt9h/

Author contributions

MS, SWT, and JS wrote the first draft of the manuscript. MS, JSKWN, HT, and PAM designed the study and collected the data. JS performed the statistical analyses. All authors were involved in the interpretation of the meta-analyses, read, revised, and approved the final manuscript.

REFERENCES

1. Amrhein, V., Greenland, S., & McShane, B. (2019). Scientists rise up against statistical significance. *Nature*, *567*(7748), 305–307. https://doi.org/10.1038/d41586-019-00857-9
2. Amrhein, V., Trafimow, D., & Greenland, S. (2019). Inferential Statistics as Descriptive Statistics: There Is No Replication Crisis if We Don't Expect Replication. *The American Statistician*, *73*(sup1), 262–270. https://doi.org/10.1080/00031305.2018.1543137
3. Balsalobre-Fernández, C., Kuzdub, M., Poveda-Ortiz, P., & Campo-Vecino, J. D. (2016). Validity and Reliability of the PUSH Wearable Device to Measure Movement Velocity During the Back Squat Exercise. *Journal of Strength and Conditioning Research*, *30*(7), 1968–1974. https://doi.org/10.1519/JSC.0000000000001284
4. Banyard, H. G., Nosaka, K., & Haff, G. G. (2017). Reliability and Validity of the Load-Velocity Relationship to Predict the 1RM Back Squat. *Journal of Strength and Conditioning Research*, *31*(7), 1897–1904. https://doi.org/10.1519/JSC.0000000000001657
5. Bautista, I. J., Chirosa, I. J., Chirosa, L. J., Martín, I., González, A., & Robertson, R. J. (2014). Development and Validity of a Scale of Perception of Velocity in Resistance Exercise. *Journal of Sports Science & Medicine*, *13*(3), 542–549.
6. Bautista, I. J., Chirosa, I. J., Robinson, J. E., Chirosa, L. J., & Martínez, I. (2016). Concurrent Validity of a Velocity Perception Scale to Monitor Back Squat Exercise Intensity in Young Skiers. *The Journal of Strength & Conditioning Research*, *30*(2), 421–429. https://doi.org/10.1519/JSC.0000000000001112

7. Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01
8. Bürkner, P.-C. (2018). Advanced Bayesian Multilevel Modeling with the R Package brms. *The R Journal*, *10*(1), 395. https://doi.org/10.32614/RJ-2018-017
9. Cumming, G. (2014). The New Statistics: Why and How. *Psychological Science*, *25*(1), 7–29. https://doi.org/10.1177/0956797613504966
10. Dorrell, H. F., Smith, M. F., & Gee, T. I. (2020). Comparison of Velocity-Based and Traditional Percentage-Based Loading Methods on Maximal Strength and Power Adaptations. *The Journal of Strength & Conditioning Research*, *34*(1), 46–53. https://doi.org/10.1519/JSC.0000000000003089
11. Gantois, P., Nakamura, F. Y., Alcazar, J., Fortes, L. de S., Pareja-Blanco, F., & Fonseca, F. de S. (2021). *The effects of different intra-set velocity loss thresholds on lower-limb adaptations to resistance training in young adults: A systematic review and meta-analysis*. SportRxiv. https://doi.org/10.31236/osf.io/v3tr9
12. Gardner, M. J., & Altman, D. G. (1986). Confidence intervals rather than P values: Estimation rather than hypothesis testing. *British Medical Journal (Clinical Research Ed.)*, *292*(6522), 746–750.
13. Kay, M. (2021). *tidybayes: Tidy Data and Geoms for Bayesian Models*. Zenodo. https://doi.org/10.5281/zenodo.5138624
14. Kruschke, J. K., & Liddell, T. M. (2018). The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. *Psychonomic Bulletin & Review*, *25*(1), 178–206. https://doi.org/10.3758/s13423-016-1221-4
15. Lagally, K. M., & Costigan, E. M. (2004). Anchoring Procedures in Reliability of Ratings of Perceived Exertion during Resistance Exercise. *Perceptual and Motor Skills*, *98*(3_suppl), 1285–1295. https://doi.org/10.2466/pms.98.3c.1285-1295
16. Lakens, D. (2021). *Sample Size Justification*. PsyArXiv. https://doi.org/10.31234/osf.io/9d3yf
17. Lazarus, A., Halperin, I., Vaknin, G. J., & Dello Iacono, A. (2021). Perception of changes in bar velocity as a resistance training monitoring tool for athletes. *Physiology & Behavior*, *231*, 113316. https://doi.org/10.1016/j.physbeh.2021.113316

18. Lenth, R. V., Buerkner, P., Herve, M., Love, J., Riebl, H., & Singmann, H. (2021). *emmeans: Estimated Marginal Means, aka Least-Squares Means* (1.6.2-1). https://CRAN.R-project.org/package=emmeans
19. Martínez-Cava, A., Hernández-Belmonte, A., Courel-Ibáñez, J., Morán-Navarro, R., González-Badillo, J. J., & Pallarés, J. G. (2020). Reliability of technologies to measure the barbell velocity: Implications for monitoring resistance training. *PLOS ONE*, *15*(6), e0232465. https://doi.org/10.1371/journal.pone.0232465
20. McGuigan, M. R. M., & Wilson, B. D. (1996). Biomechanical Analysis of the Deadlift. *The Journal of Strength & Conditioning Research*, *10*(4), 250–255.
21. McShane, B. B., Gal, D., Gelman, A., Robert, C., & Tackett, J. L. (2019). Abandon Statistical Significance. *The American Statistician*, *73*(sup1), 235–245. https://doi.org/10.1080/00031305.2018.1527253
22. Mengersen, K. L., Drovandi, C. C., Robert, C. P., Pyne, D. B., & Gore, C. J. (2016). Bayesian Estimation of Small Effects in Exercise and Sports Science. *PLOS ONE*, *11*(4), e0147311. https://doi.org/10.1371/journal.pone.0147311
23. Noble, B. J., & Robertson, R. J. (1996). *Perceived exertion*. Human Kinetics.
24. Orange, S. T., Hritz, A., Pearson, L., Jeffries, O., Jones, T. W., & Steele, J. (2022). Comparison of the effects of velocity-based vs. traditional resistance training methods on adaptations in strength, power, and sprint speed: A systematic review, meta-analysis, and quality of evidence appraisal. *Journal of Sports Sciences*, *0*(0), 1–15. https://doi.org/10.1080/02640414.2022.2059320
25. Pareja-Blanco, F., Alcazar, J., Cornejo-Daza, P. J., Sánchez-Valdepeñas, J., Rodriguez-Lopez, C., Hidalgo-de Mora, J., Sánchez-Moreno, M., Bachero-Mena, B., Alegre, L. M., & Ortega-Becerra, M. (2020). Effects of velocity loss in the bench press exercise on strength gains, neuromuscular adaptations, and muscle hypertrophy. *Scandinavian Journal of Medicine & Science in Sports*, *30*(11), 2154–2166. https://doi.org/10.1111/sms.13775
26. Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Sanchis-Moysi, J., Dorado, C., Mora-Custodio, R., Yáñez-García, J. M., Morales-Alamo, D., Pérez-Suárez, I., Calbet, J. a. L., & González-Badillo, J. J. (2017). Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scandinavian Journal of Medicine & Science in Sports*, *27*(7), 724–735. https://doi.org/10.1111/sms.12678

27. Pedersen, T. L. (2020). *patchwork: The Composer of Plots* (1.1.1). https://CRAN.R-project.org/package=patchwork
28. Pinheiro, J., & Bates, D. (2000). *Mixed-Effects Models in S and S-PLUS*. Springer-Verlag. https://doi.org/10.1007/b98882
29. Richens, B., & Cleather, D. J. (2014). The relationship between the number of repetitions performed at given intensities is different in endurance and strength trained athletes. *Biology of Sport*, *31*(2), 157–161. https://doi.org/10.5604/20831862.1099047
30. Romagnoli, R., & Piacentini, M. F. (2022). Perception of Velocity during Free-Weight Exercises: Difference between Back Squat and Bench Press. *Journal of Functional Morphology and Kinesiology*, *7*(2), 34. https://doi.org/10.3390/jfmk7020034
31. Sánchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise*, *43*(9), 1725–1734. https://doi.org/10.1249/MSS.0b013e318213f880
32. Sindiani, M., Lazarus, A., Iacono, A. D., & Halperin, I. (2020). Perception of changes in bar velocity in resistance training: Accuracy levels within and between exercises. *Physiology & Behavior*, *224*, 113025. https://doi.org/10.1016/j.physbeh.2020.113025
33. Thompson, S. W., Rogerson, D., Dorrell, H. F., Ruddock, A., & Barnes, A. (2020). The Reliability and Validity of Current Technologies for Measuring Barbell Velocity in the Free-Weight Back Squat and Power Clean. *Sports (Basel, Switzerland)*, *8*(7). https://doi.org/10.3390/sports8070094
34. Thompson, S. W., Rogerson, D., Ruddock, A., Banyard, H. G., & Barnes, A. (2021). Pooled Versus Individualized Load–Velocity Profiling in the Free-Weight Back Squat and Power Clean. *International Journal of Sports Physiology and Performance*, *16*(6), 825–833. https://doi.org/10.1123/ijspp.2020-0534
35. van den Tillaar, R., & Ball, N. (2020). Push-Ups are Able to Predict the Bench Press 1-RM and Constitute an Alternative for Measuring Maximum Upper Body Strength Based on Load-Velocity Relationships. *Journal of Human Kinetics*, *73*, 7–18. https://doi.org/10.2478/hukin-2019-0133
36. Weakley, J., Mann, B., Banyard, H., McLaren, S., Scott, T., & Garcia-Ramos, A. (2021). Velocity-Based Training: From Theory to Application. *Strength &*

Conditioning Journal, *43*(2), 31–49. https://doi.org/10.1519/SSC.0000000000000560

37. Weakley, J., Ramirez-Lopez, C., McLaren, S., Dalton-Barron, N., Weaving, D., Jones, B., Till, K., & Banyard, H. (2020). The Effects of 10%, 20%, and 30% Velocity Loss Thresholds on Kinetic, Kinematic, and Repetition Characteristics During the Barbell Back Squat. *International Journal of Sports Physiology and Performance*, *15*(2), 180–188. https://doi.org/10.1123/ijspp.2018-1008
38. Weakley, J., Wilson, K., Till, K., Banyard, H., Dyson, J., Phibbs, P., Read, D., & Jones, B. (2020). Show Me, Tell Me, Encourage Me: The Effect of Different Forms of Feedback on Resistance Training Performance. *The Journal of Strength & Conditioning Research*, *34*(11), 3157–3163. https://doi.org/10.1519/JSC.0000000000002887
39. Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis* (2nd ed.). Springer International Publishing. https://doi.org/10.1007/978-3-319-24277-4
40. Wilkinson, G. N., & Rogers, C. E. (1973). Symbolic Description of Factorial Models for Analysis of Variance. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, *22*(3), 392–399. https://doi.org/10.2307/2346786
41. Yarkoni, T. (2020). The generalizability crisis. *Behavioral and Brain Sciences*, 1–37. https://doi.org/10.1017/S0140525X20001685