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ABSTRACT

The aim of this study was to investigate the differences and long-term reliability in perceptual, metabolic, and neuromuscular responses to velocity loss resistance training protocols. Using a repeated, counterbalanced, crossover design, twelve team-sport athletes completed 5-sets of barbell back-squats at a load corresponding to a mean concentric velocity of ~0.70 $m \cdot s^{-1}$. On different days, repetitions were performed until a 10%, 20% or 30% velocity loss was attained, with outcome measures collected after each set. Sessions were repeated after four-weeks. There were substantial between-protocol differences in post-set differential ratings of perceived exertion (dRPE, i.e., breathlessness and leg muscles, AU) and blood lactate concentration (B[La], $mmol \cdot L^{-1}$), such that 30%>20%>10% by small to large magnitudes. Differences in post-set countermovement jump (CMJ) variables were small for most variables, such that 30%<20%<10%. Standard deviations representing four-week variability of post-set responses to each protocol were: dRPE, 8–11; B[La], 0.8–1.0; CMJ height, 1.6–2.0; CMJ PPO, 1.0–1.8; CMJ PCV, 0.04–0.06; CMJ 100ms-Impulse, 5.7–11.9. Velocity loss thresholds control the magnitude of perceptual, metabolic, and neuromuscular responses to resistance training. For practitioners wanting to reliably prescribe training that can induce a given perceptual, metabolic, or neuromuscular response, it is strongly advised that velocity-based thresholds are implemented.

Keywords: Velocity-based training; Countermovement Jump; Lactate; Rating of perceived exertion; Reliability

Introduction

Velocity-based training (VBT) is a resistance training method that can control for changes in physical characteristics and daily readiness (Garcia-Ramos et al. 2019a; Garcia-Ramos et al. 2019b; Mann et al. 2015). Furthermore, it can standardise the external load that is applied to an athlete within each training session through the use of relative velocity loss thresholds (Weakley et al. 2019a). When velocity loss thresholds are applied during resistance training, an exercise set is terminated at a pre-defined mean concentric velocity. For example, if a 10% velocity loss threshold was applied to a set of the back squat that had an initial repetition speed of 0.70 $m \cdot s^{-1}$, the set would be terminated when the barbell velocity reached 0.63 $m \cdot s^{-1}$ (Weakley et al. 2019a). This method of exercise prescription allows the practitioner to control for differences in individual strength endurance characteristics and controls for changes in force generating capacity as athletes exercise (Weakley et al. 2019a).

The use of velocity loss thresholds during the prescription of resistance training has received increasing attention due to its ability to: (1) control for kinetic and kinematic outputs, and (2) influence neuromuscular adaptations. Recently, we demonstrated that the implementation of mean concentric velocity loss threshold protocols during training can mitigate changes in mean and peak velocity, power, and force across multiple sets of the back squat (i.e., trivial to small changes across all variables) (Weakley et al. 2019a). Moreover, differences between athletes were trivial to small. Additionally, Pareja-Blanco et al. (2017) have shown that strength, power, and hypertrophic adaptations can be altered when differing thresholds are applied (e.g., greater increases in cross-sectional area but losses in the fastest myosin heavy chain isoforms during 40% velocity loss conditions occur *vs.* greater increases in strength and power during 20% velocity loss conditions). However, the acute neuromuscular fatigue and internal responses to free-weight resistance training have not been established with these thresholds. This is despite previous research highlighting that varying amounts of velocity loss during resistance exercise cause varying metabolic outcomes following training (González-Badillo et al. 2017).

Changes in training outcomes are of very little value without precise, thorough, and in-depth information about the exercise training itself (Mujika 2013). Therefore, as well as understanding the kinetic and kinematic outputs of velocity loss training (Weakley et al. 2019a), it is important to establish the associated internal training loads that cause chronic structural and functional adaptations. In resistance training, physiological internal load can be quantified using perceptual (e.g., differential rating of perceived exertion (dRPE)) and metabolic measures (e.g., lactate). Given the difficulties of accurately measuring biomechanical internal loads (i.e., mechanical stress and tissue damage) even in laboratory settings (Vanrenterghem et al. 2017), markers of neuromuscular fatigue, such as absolute or mechanically-derived performance during jump tasks, have previously been used as surrogate indicators (Weakley et al. 2017c).

The ability of velocity loss protocols to control for within-session changes in internal load and neuromuscular fatigue have not been well established, with previous research only demonstrating general relationships between velocity loss and these outcomes (González-Badillo et al. 2017). Furthermore, these outcomes have not been demonstrated in free-weight resistance exercises (e.g., the barbell back squat). We are also unaware of any study that has assessed the long-term reliability (i.e., variability) of internal load and acute neuromuscular fatigue markers in response to different velocity loss protocols. This is an important consideration for VBT given it aims to control for changes in neuromuscular characteristics and daily readiness, which are likely to fluctuate over long-term periods. Therefore, we aimed to describe within and between-condition differences in perceptual, metabolic, and neuromuscular responses of 10%, 20%, and 30% velocity loss protocols in the free-weight barbell back squat. Additionally, we aimed to determine the typical four-week variability of these internal load and acute neuromuscular fatigue markers in response to each protocol.

METHODS

Design

We utilised a repeated, counterbalanced, crossover design to assess the effects of different velocity loss thresholds on within-session perceptual, metabolic, and neuromuscular responses during the barbell back squat. Participants visited the laboratory on seven occasions, including a familiarisation session, and three resistance training protocols, which were completed twice. Each protocol (10%, 20% and 30%) was completed once within 9 days, in a counterbalanced manner, allowing for 72 hours rest between-sessions. Protocols were then repeated after four weeks, with each participant completing protocols in the same order as initially prescribed to standardize the test-retest duration. The velocity loss protocols have previously been described in detail elsewhere (Weakley et al. 2019a).

Participants

Twelve male team sport athletes (mean ± standard deviation [SD]; age: 23 ± 3 years; body mass: 87.4 ± 12.2 kg; height: 179 ± 6 cm) from a British University and Colleges Super Rugby club (United Kingdom) volunteered to participate in our study. All athletes had at least two years resistance training experience (Weakley et al. 2017a) and had been habitually completing this exercise at least twice a week for three months without interruption. Testing occurred during the off-season period of the rugby union playing calendar. During the familiarisation session, athletes were explained the study design, provided the opportunity to ask questions, and gave written consent. Athletes were also required to demonstrate the back-squat exercise during pre-study screening to ensure the strict technique requirements of the study were met. Screening was performed by an accredited strength and conditioning coach, who also monitored technique during all experimental sessions. All experimental procedures were approved by the Leeds Beckett University's ethics committee.

Procedures:

Resistance training sessions

Testing was completed at the same time of day and required athletes to have not completed any strenuous exercise in the preceding 48 hours. On each occasion, athletes arrived, were required to perform a 15-minute standardisation period that involved sitting quietly, and then provided a fingertip blood sample. Athletes then completed a standardised warm-up which consisted of dynamic movements and stretches. At the conclusion of the warm-up, three minutes was provided and two countermovement jumps (CMJs) were performed on a portable force plate (NMP Technologies Ltd., ForceDecks Model FD4000a, London, UK) which sampled at 1000 Hz. Following this, a squat specific warm-up was completed which consisted of eight repetitions with an empty barbell (Eleiko Sport AB, Halmstad, Sweden), this was followed by three sets of 3-5 repetitions at self-selected submaximal loads (Weakley et al. 2017b). Throughout the warm up and training sessions, all athletes were required to squat so that the top of the knee was parallel with the fold between the torso and thigh (observed by the lead researcher). During the warm-up, the mean concentric velocity of all repetitions was monitored by a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) which has been shown to demonstrate acceptable reliability and validity (Banyard et al. 2017; Dorrell et al. 2019).

Following the squat specific warm-up, the load that elicited a barbell mean concentric velocity of 0.70 ± 0.01 $m \cdot s^{-1}$ was found according to previously detailed methods (Weakley et al. 2019a). This velocity was selected as previous research has investigated the kinetic, kinematic, and repetition characteristics that occur when training with these protocols (Weakley et al. 2019a). Briefly, the primary investigator (who was present during all testing occasions) placed a load that was 70% of the subjects estimated 1RM on the bar. The athletes then completed two repetitions with this load followed by a three-minute recovery period. If the mean concentric velocity of the fastest repetition from this estimated 70% 1RM load was outside of the 0.70 ± 0.01 $m \cdot s^{-1}$ range, the external load was adjusted. Adjustments were made according to previous research that required adjustments of ± 5% of estimated 1RM when mean concentric velocity was 0.06 $m \cdot s^{-1}$ higher or lower than 0.70 $m \cdot s^{-1}$ (Weakley et al. 2019a). Smaller adjustments (e.g. 0.5-1.0kg) were used when within this 0.06 $m \cdot s^{-1}$ range (e.g. 0.67 $m \cdot s^{-1}$).

Once a load that enabled a barbell mean concentric velocity of 0.70 ± 0.01 $m \cdot s^{-1}$ was found on each testing occasion, participants were provided a five-minute recovery and then completed five sets of the back squat with either a 10%, 20%, or 30% velocity loss threshold applied. By applying these set velocity thresholds, athletes were required to terminate the exercise set at 0.63 $m \cdot s^{-1}$ in the 10% condition, 0.56 $m \cdot s^{-1}$ in the 20% condition, and 0.49 $m \cdot s^{-1}$ in the 30% condition. Following the completion of each set, three minutes recovery was provided. During this period, a CMJ, fingertip blood sample, and dRPE for breathlessness and lower peripheries were obtained (refer to Figure 1). In sets 2-5, the mean concentric velocity of the initial repetition of the set was required to be 0.70 ± 0.06 $m \cdot s^{-1}$ (Weakley et al. 2019a). If the velocity of the first repetition of sets 2-5 was not within the 0.70 ± 0.06 $m \cdot s^{-1}$ range, an additional 30 seconds recovery was provided. After this additional 30 second recovery period, athletes performed another single repetition. If the concentric velocity of the barbell was within the 0.70 ± 0.06 $m \cdot s^{-1}$ range, the set continued to the prescribed velocity loss threshold. However, if barbell velocity from this second attempt was not within this range, the load was adjusted by ± 5% of estimated 1RM and a further 30 seconds recovery was provided. Once a load adjustment had been made, all athletes were found to be able to attain a barbell velocity within the 0.70 ± 0.06 $m \cdot s^{-1}$ range on the following repetition and the set continued to the prescribed velocity loss threshold. Visual feedback of barbell mean concentric velocity was provided during every set and repetition to help promote maximal intent during the concentric portion of the exercise (Weakley et al. 2019d; Wilson et al. 2017; Wilson et al. 2018).

Insert Figure 1 Here

Outcome measures

Collection of differential-rating of perceived exertion

During familiarisation, participants were given instruction on the definition of effort perception and its scaling (Pageaux et al. 2016). This included the importance of separating RPE from other exercise related sensations such as pain, discomfort and fatigue. Instruction was also given on how to appraise dRPE, such that rating of perceived exertion of breathlessness (RPE-B) depends mainly on breathing rate and/or heart rate, and rating of perceived exertion of the lower peripheries (RPE-L) depends mainly on the strain and exertion in the leg muscles (e.g., thighs, glutes, calves). These instructions were verbally reiterated during the familiarisation session, in which dRPE were collected. Following each training set, participants confidentially provided ratings by pointing to verbal anchors on the CR100 scale (McLaren et al. 2018). Participants were instructed that their ratings should reflect the perceptions of effort experienced during the previous set.

Metabolic assessment

Blood lactate (B[La]) concentration was analysed before, during, and after the exercise protocols using a YSI 2300 Stat Plus (Yellow Springs, Ohio, USA). All samples were obtained with participants in a seated position. After sterilising the index finger, a puncture was made with a spring-loaded single use disposable lancet. The first drop of blood was wiped away to avoid contamination and the participant's blood was then collected in a 25-µL microvette tube. The samples were then immediately analysed for B[La] concentration. The testing device was calibrated prior to each session using assays of a known concentration.

Countermovement jump assessment

All CMJ assessments were completed using a force platform (NMP Technologies Ltd., ForceDecks Model FD4000a, London, UK) which sampled at a rate of 1000 Hz. Participants performed two jumps before, during, and after the training protocols with feet placed approximately shoulder width apart and with hands placed on hips. Participants lowered themselves to a self-selected depth and jumped as high as possible. Jump height, peak concentric velocity, concentric relative peak power output (PPO), and impulse at 100ms of the concentric phase were chosen due to their satisfactory between-day reliability (Roe et al.

2016; Roe et al. 2017; Sawczuk et al. 2017) and common use in research (Weakley et al. 2018; Weakley et al. 2019b; Weakley et al. 2019c).

Statistical analyses

Visual inspection of raw data via histograms and Q–Q plots showed approximate normal distribution for the perceptual, metabolic and neuromuscular responses to each set. Descriptive summary statistics are therefore presented as the mean ± standard deviation (SD). We used linear mixed effect models (SPSS version 24, IBM, Armonk, NY, US) to compare the perceptual, metabolic and neuromuscular responses within and between each velocity loss protocol. First, set number was mean centred and re-scaled (ranging from -0.5 to 0.5) before being specified as a fixed effect (covariate, with intercept) to compare the linearized change in outcome measures across the five sets. Protocol (10%, 20%, or 30% velocity loss) was then specified as a fixed effect (factor, with intercept) and interacted with sets to compare the typical (mean) set perceptual, metabolic and neuromuscular responses between each protocol (i.e. difference in intercepts). Models were fit with a random intercept for athlete and a random slope for set, using an unstructured covariance matrix, to account for individual differences in the linearized change across the five sets. Finally, a random effect for session was included, without an intercept and using a variance components structure, to estimate the four-week variability (expressed as a SD) in an athlete's set perceptual, metabolic and neuromuscular responses to each protocol.

Uncertainty in all outcome measures was expressed as 90% confidence intervals (CI). We used non-clinical magnitude-based decisions (Batterham and Hopkins 2006; Hopkins 2007) to provide an interpretation of the size and uncertainty of all effects. Standard deviations for the intercept (between-athlete), session and residual were pooled and multiplied by thresholds of 0.2, 0.6, 1.2, and 2.0 anchor small, moderate, large, and very large effects, respectively (Batterham and Hopkins 2006). Subsequently, the chance of an effect being substantial or trivial was calculated using a customised spreadsheet (Hopkins 2007) by converting the *t* statistic for the effect in relation to the threshold (effect – threshold/ standard error of the effect) to a continuous probability via the one-tailed *t*-distribution. Quantitative probabilities are then assigned to the following qualitative probabilistic terms: possibly, 25.0–74.9%; likely, 75.0–94.9%; very likely, 95.0–99.5%; almost certainly > 99.5% (Batterham and Hopkins 2006). The effect was declared unclear if the chance of being both substantially positive and negative was ≥ 5%.

RESULTS

Descriptive data and within-protocol changes

Raw data for each set and protocol is displayed in Figure 2. The set-to-set changes in perceptual, metabolic and neuromuscular responses to each protocol are displayed in Figure 3 and 4. There was a likely moderate increase in RPE-L through the 10% protocol, with both 20% and 30% protocols resulting in most likely large to possibly very large increases. The increase in RPE-B across 5 sets was very likely small to possibly moderate for 10%, very likely moderate to possibly large for 20%, and likely large for 30%. B[La] concentration reduced across the 5 sets by a very likely small to possibly moderate magnitude in the 10% protocol. There was a possibly small increase to possibly trivial change in B[La] for the 20% protocol and the change throughout the 30% protocol was unclear. There was a possibly to likely small reduction in CMJ variables throughout the 10% protocol, possibly trivial to possibly small reductions for the 20% protocol, and possibly to likely small reductions for 30% protocol.

Insert Figure 2 here

Insert Figure 3 and 4 here

Between-protocol differences

The differences in typical (mean) set perceptual, metabolic and neuromuscular responses between each velocity loss protocol are shown in Table 1. Associated grand means and the pooled SD are shown in Figure 1 A and B. There were clear and substantial differences in perceptual and metabolic response to each protocol, such that 30% > 20% > 10%. When compared with the 10% protocol, differences for 20% and 30% protocols were most likely moderate to possibly very large. Differences between 20% and 30% protocols were most likely small to most likely moderate. Most between-protocol differences in CMJ variables were clear and substantial, such that 30% < 20% < 10%. There was a likely trivial difference in impulse between 10% and 20% protocols, as well as 20% and 30% protocols. The difference in PPO between 20% and 30% protocols was possibly trivial/ possibly small. Differences in the remaining comparisons were likely small to possibly moderate.

Between-protocol reliability of perceptual, metabolic, and neuromuscular outcomes

The four-week variability of set perceptual, metabolic and neuromuscular responses to each velocity loss protocol are shown in Table 2.

DISCUSSION

Our study investigated the perceptual, metabolic, and neuromuscular responses to 10%, 20%, and 30% velocity loss thresholds during five sets of the free-weight back squat. We found perceptual (i.e. dRPE) and metabolic responses to increase as a function of the applied threshold; with greater thresholds producing greater responses. A similar, inverse pattern was evident for neuromuscular responses, although these between-protocol differences were of a much smaller magnitude when compared with perceptual and metabolic responses. Regarding within-protocol effects, perceptual and metabolic responses generally increased across the five sets, with greater increments in the 20% and 30% condition compared to the 10% condition. Conversely, the reductions in neuromuscular performance were trivial to small. Finally, an important finding was the highly reproducible perceptual, metabolic, and neuromuscular responses to each velocity loss protocol, as evidenced by the standard deviations representing the four-week variability of post-set responses to each protocol. Collectively, as shown in Table 2, our findings demonstrate not only that velocity loss thresholds mediate the magnitude of perceptual, metabolic, and neuromuscular responses to resistance training, but that these responses are reliable over long-term periods.

Changes in post-set CMJ height across the five sets tended to show near linear decreases in performance with each 10% increase in velocity loss. Furthermore, changes in relative PPO, peak concentric velocity, and impulse at 100ms tended to show trivial to small changes with greater velocity losses. Additionally, within-each protocol, neuromuscular performance demonstrated trivial to small changes (i.e. from set 1 to 5). This suggests that prescribing different velocity loss resistance training protocols (i.e., 10%, 20%, or 30%) induces differing amounts of neuromuscular fatigue, but this fatigue does not substantially accumulate throughout exercise (e.g., within-protocol). These responses are unique to relative velocity loss termination points and likely due to the autoregulation that occurs when they are implemented (Weakley et al. 2019a). This supports earlier work by Rodriguez-Rosell et al. (2018) that has demonstrated similar relationships. However, this previous research had only utilised exercises within a Smith machine, which limited application to more commonly utilised free-weight exercises (e.g., free-weight barbell back squat). Considering these findings, practitioners may wish to use these novel outcomes to their advantage. For example, minimal losses in neuromuscular function may be desirable (e.g., in the latter half of a training week) while still requiring sufficient training volume. Thus, practitioners may prescribe a 10% velocity loss across multiple sets as this would minimise absolute losses in neuromuscular function while concurrently mitigating the accumulation of within-session fatigue.

With each incremental increase in velocity loss protocol (30% > 20% > 10%), moderate increases in B[La] were observed (~1.7-1.9 mmol·L^{-1}). These differences are likely due to the greater volume (i.e., number of repetitions) completed for protocols with greater velocity loss (Weakley et al. 2019a). These findings are supported by our previous research which showed greater metabolic responses accompany increases in resistance training efficiency (i.e., kg's lifted per minute) (Weakley et al. 2017c). In our present study, however, the rate at which B[La] accumulated within a given protocol, was vastly different. The 10% condition demonstrated a reduction in B[La] across the five sets, which may be due to the gradual decline of lactate that was developed during the standardised warm-up and indicate a greater reliance on adenosine triphosphate and phosphocreatine, while the within-session change across the 30% condition was unclear. This uncertainty can potentially be attributed to the greater between set variability in repetitions that occurs when completing training with 30% velocity loss and the ability of VBT prescription to allow for auto-regulation of the number of repetitions per set (Weakley et al. 2019a).

Small to large increases in dRPE were observed with corresponding increases in velocity loss, such that larger velocity loss thresholds were perceived 'harder'. However, while the rate of change was consistent in both perceptual measures within the 10% condition, RPE-L increased across sets at a greater rate than RPE-B in the 20% and 30% condition. This was particularly prevalent in the 20% condition. These differing changes in perceived central and peripheral (i.e. neuromuscular) effort might support previous evidence suggesting that, in repeated bouts of short high-intensity exercise, neuromuscular fatigue is more pronounced than changes in oxygen uptake (Balsom et al. 1992). Thus, when prescribing larger velocity loss thresholds (e.g., 20% and 30%), perceptions of breathlessness and leg muscle exertion may generally be similar, but leg muscle exertion may demonstrate a greater perceived increase within a session across repeated sets.

This is the first study to assess the long-term reliability of internal responses and neuromuscular fatigue to resistance training protocols. Reliability refers to the consistency or reproducibility of an outcome measure across repeated assessments (Hopkins 2000). Understanding the reliability of perceptual, metabolic and neuromuscular responses to VBT is therefore of particular interest to both researchers and practitioners. Estimates of within-person variability (e.g. typical error or SD) are often used to quantify reliability. Sources of variability include both technical measurement error and random biological variation (Hopkins 2000). The latter is said to increase with longer durations between test-retest periods (Hopkins 2000), making the evaluations of long-term reliability an important consideration to any intervention (Hurst et al. 2018).

In our study, participants performed each protocol twice, four weeks apart, with no control or restriction given on any aspect of training or lifestyle between the two sessions. External load (weight lifted) was, however, regulated in each session, such that an initial mean concentric velocity of 0.70 ± 0.01 $m\cdot s^{-1}$ was attained and small adjustments were made on a set-to-set basis to maintain consistent initial barbell velocity. Subsequently, after accounting for several sources of systematic change (i.e. over 5 sets) and random variability (between-participant differences in absolute performance and the change over 5 sets), we were able to estimate SDs representing the four-week reliability in response to each set (Table 2). Interestingly, these SDs were of a similar magnitude to those reported in tightly controlled, short term (i.e. < 1 week) studies investigating the reliability of perceptual, metabolic and neuromuscular responses to no exercise (i.e., pure control (Cormack et al. 2008; Hori et al. 2009)), resistance training (Day et al. 2009), and other forms of short-bout, neuromuscular demanding exercise (Dal Pupo et al. 2014). This important finding demonstrates that relative velocity loss thresholds enable practitioners to reliably control for the internal and neuromuscular response to resistance training, even over long-term periods that are subject to large biological variation.

While our study demonstrates the practical nature of implementing velocity loss thresholds and provides evidence of its reproducibility, it is not without limitations. First, we acknowledge that differing starting velocities may alter neuromuscular, metabolic, and perceptual outcomes whilst training. However, due to previous research demonstrating the kinetic and kinematic outcomes that occur with these thresholds and initial starting velocities (Weakley et al. 2019a), it was felt necessary to demonstrate the internal responses to this form of resistance training prescription at these velocities. Furthermore, previous evidence has suggested that velocity loss thresholds follow similar trends across a range of initial starting velocities (Pareja-Blanco et al. 2017). Second, it should be highlighted that while external and internal responses have been demonstrated, the short-term fatigue and physical performance responses (e.g., 24 hours post-training) to training with different velocity loss thresholds are still unknown. Thus, future research is still required to understand how this method of training prescription will affect subsequent exercise sessions.

Despite athletes having highly variable strength endurance characteristics, prescribing velocity loss thresholds can control the magnitude of perceptual, metabolic, and neuromuscular responses to resistance training, with these responses being reliable over long-term (i.e. 4-

week) periods. Our present data challenges traditional percentage-based prescription methods, which demonstrates large variance between-athletes in repetition and subsequent responses. Consequently, practitioners and scientists should apply velocity loss thresholds when resistance training to: 1) achieve pre-determined internal fatigue responses during training; 2) mitigate the highly variable strength endurance characteristics of athletes; and 3) confidently prescribe training loads that can induce similar internal responses across time.

From our findings, we recommend that relative velocity loss thresholds are used to guide resistance exercise prescription. This can efficiently be implemented into training by asking athletes to note exercise velocity during the warm up and the first repetition of each set. By implementing 10%, 20%, and 30% velocity loss thresholds during resistance training, divergent perceptual, metabolic and neuromuscular responses will occur with a high level of reproducibility. For example, when compared to a 20% threshold, 30% thresholds will induce greater metabolic responses, larger reductions in jump height, and increased perceptions of effort. Alternatively, 10% thresholds will cause smaller changes from homeostasis and be perceived to require less physical effort. Consequently, we recommend that smaller thresholds (e.g., 10%) are utilised to moderate internal responses during congested training periods or when high amounts of neuromuscular and metabolic fatigue are not favourable (e.g., close to competition or when trying to develop muscular power). Additionally, these smaller thresholds may be favourable in sports that require greater kinetic and kinematic outputs but low metabolic and neuromuscular disturbance (e.g., throwing events). Alternatively, it is advised that larger relative thresholds are applied (e.g., 30%) when trying to develop a greater internal response which may favour greater morphological adaptations (e.g., during muscular hypertrophy and strength endurance mesocycles). Finally, our data suggests that, when utilising these velocity loss thresholds, practitioners can have confidence in the reproducibility of responses across time.

REFERENCES

1. Balsom P, Seger J, Sjödin B, Ekblom B (1992) Maximal-intensity intermittent exercise: effect of recovery duration. Int J Sports Med 13:528-533. doi: 10.1055/s-2007-1021311
2. Banyard, HG, Nosaka, K., Sato, K. and Haff, GG (2017) Validity of Various Methods for Determining Velocity, Force, and Power in the Back Squat. *Int J Sports Physiol Perform* 12:1170-1176. doi: 10.1123/ijspp.1.1.50
3. Batterham AM, Hopkins WG (2006) Making meaningful inferences about magnitudes. Int J Sport Phys Perf 1:50-57. doi: 10.1123/ijspp.1.1.50
4. Cormack SJ, Newton RU, McGuigan MR, Doyle TL (2008) Reliability of measures obtained during single and repeated countermovement jumps. Int J Sport Phys Perf 3:131-144. doi: 10.1123/ijspp.3.2.131
5. Dal Pupo J, Gheller RG, Dias JA, Rodacki AL, Moro AR, Santos SG (2014) Reliability and validity of the 30-s continuous jump test for anaerobic fitness evaluation. J Sci Med Sport 17:650-655. doi: 10.1016/j.jsams.2013.09.007
6. Day ML, Mcguigan MR, Brice G, Foster C (2004) Monitoring exercise intensity during resistance training using the session RPE scale. J Strength Cond Res 18:353-358. doi: 10.1519/R-13113.1
7. Dorrell, HF, Moore, JM, Smith, MF and Gee, TI (2019) Validity and reliability of a linear positional transducer across commonly practised resistance training exercises. J Sports Sci 37:67-73. doi: 10.1080/02640414.2018.1482588
8. García-Ramos A, Ulloa-Díaz D, Barboza-González P, Rodríguez-Perea Á, Martínez-García D, Quidel-Catrilelbún M, Guede-Rojas F, Cuevas-Aburto J, Janicijevic D, Weakley J (2019) Assessment of the load-velocity profile in the free-weight prone bench pull exercise through different velocity variables and regression models. PLOS ONE 14:e0212085. doi: 10.1371/journal.pone.0212085
9. García-Ramos A, Ulloa-Díaz D, Barboza-González P, Rodríguez-Perea Á, Martínez-García D, Quidel-Catrilelbún M, Guede-Rojas F, Cuevas-Aburto J, Janicijevic D, Weakley J (2019) Reliability and validity of different methods of estimating the one-repetition maximum during the free-weight prone bench pull exercise. J Sports Sci 37:2205-2212. doi: 10.1080/02640414.2019.1626071
10. González-Badillo JJ, Yañez-García JM, Mora-Custodio R, Rodríguez-Rosell D (2017) Velocity Loss as a Variable for Monitoring Resistance Exercise. Int J Sports Med 38:217-225. doi: 10.1055/s-0042-120324
11. Hopkins WG (2000) Measures of reliability in sports medicine and science. Sports Med 30:1-15. doi: 10.2165/00007256-200030010-00001
12. Hopkins WG (2007) A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. Sportsci 11:16-20.
13. Hori N, Newton RU, Kawamori N, McGuigan MR, Kraemer WJ, Nosaka K (2009) Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. J Strength Cond Res 23:874-882. doi: 10.1519/JSC.0b013e3181a00ca2

14. Hurst C, Batterham AM, Weston KL, Weston M (2018) Short- and long-term reliability of leg extensor power measurement in middle-aged and older adults. J Sport Sci 36:970-977. doi: 10.1080/02640414.2017.1346820
15. Mann JB, Ivey PA, Sayers SP (2015) Velocity-based training in football. Strength Cond J 37:52-57. doi: 10.1519/SSC.0000000000000177
16. McLaren SJ, Smith A, Spears IR, Weston M (2017) A detailed quantification of differential ratings of perceived exertion during team-sport training. J Sci Med Sport 20:290-295. doi: 10.1016/j.jsams.2016.06.011
17. Mujika I (2013) The Alphabet of Sport Science Research Starts With Q. Int J Sport Phys Perf 8:465-466. doi: 10.1123/ijspp.8.5.465
18. Pageaux B, Lepers R (2016) Fatigue Induced by Physical and Mental Exertion Increases Perception of Effort and Impairs Subsequent Endurance Performance. Front Phys 7:587. doi: 10.3389/fphys.2016.00587
19. Pareja-Blanco F, Rodríguez-Rosell D, Sánchez-Medina L, Sanchis-Moysi J, Dorado C, Mora-Custodio R, Yáñez-García J, Morales-Alamo D, Pérez-Suárez I, Calbet J (2017) Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. Scand J Med Sci Sports 27:724-735. doi: 10.1111/sms.12678
20. Rodríguez-Rosell, D., Yáñez-García, JM, Torres-Torrelo, J, Mora-Custodio, R, Marques, MC and González-Badillo, JJ (2018) Effort index as a novel variable for monitoring the level of effort during resistance exercises. J Strength Cond Res 32: 2139-2153. doi: 10.1519/JSC.0000000000002629
21. Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, Jones B (2016) Between-Day Reliability and Sensitivity of Common Fatigue Measures in Rugby Players. Int J Sport Phys Perf. 11:581-586. doi: 10.1123/ijspp.2015-0413
22. Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, Jones B (2017) To Jump or Cycle? Monitoring Neuromuscular Function in Rugby Union Players. Int J Sport Phys Perf 12:690-696. doi: 10.1123/ijspp.2016-0273
23. Sawczuk T, Jones B, Scantlebury S, Weakley J, Read D, Costello N, Darrall-Jones JD, Stokes K, Till K (2017) Between-Day Reliability and Usefulness of a Fitness Testing Battery in Youth Sport Athletes: Reference Data for Practitioners. Measure Phys Ed Ex Sci 22:11-18. doi: 10.1080/1091367X.2017.1360304
24. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B (2017) Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. Sports Med 47:2135-2142. doi: 10.1007/s40279-017-0714-2
25. Weakley J, Ramirez-Lopez C, McLaren S, Weaving D, Dalton-Barron N, Jones B, Till K, Banyard HG (2019a) The effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics during the barbell back squat. Int J Sport Phys Perf Ahead of Press. doi: 10.1123/ijspp.2018-1008
26. Weakley JJS, Till K, Darrall-Jones J, Roe GAB, Phibbs PJ, Read DB, Jones BL (2017a) The Influence of Resistance Training Experience on the Between-Day Reliability of Commonly Used Strength Measures in Male Youth Athletes. J Strength Cond Res 31:2005-2010. doi: 10.1519/JSC.0000000000001883.
27. Weakley JJS, Till K, Darrall-Jones J, Roe GAB, Phibbs PJ, Read DB, Jones BL (2019b) Strength and Conditioning Practices in Adolescent Rugby Players: Relationship with Changes in Physical Qualities. J Strength Cond Res 33:2361-2369. doi: 10.1519/JSC.0000000000001828
28. Weakley J, Till K, Sampson J, Banyard HG, Leduc C, Wilson K, Roe G, Jones B (2019c) The Effects of Augmented Feedback on Sprint, Jump, and Strength

Adaptations in Rugby Union Players Following a Four Week Training Programme. Int J Sport Phys Perf 14:1205-1211. doi: 10.1123/ijspp.2018-0523

29. Weakley JJ, Till K, Read DB, Phibbs PJ, Roe G, Darrall-Jones J, Jones BL (2017b) The Effects of Superset Configuration on Kinetic, Kinematic, and Perceived Exertion in the Barbell Bench Press. J Strength Cond Res Publish Ahead of Print. doi: 10.1519/JSC.0000000000002179
30. Weakley JJS, Till K, Read DB, Roe GAB, Darrall-Jones J, Phibbs PJ, Jones B (2017c) The effects of traditional, superset, and tri-set resistance training structures on perceived intensity and physiological responses. Euro J App Phys 117:1877-1889. doi: 10.1007/s00421-017-3680-3
31. Weakley J, Till, K., Read, D., Leduc, C., Roe, G., Phibbs, P., Darrall-Jones, J., Jones, B (2018) Jump Training in Rugby Union Players: Barbell or Hexagonal Bar? J Strength Cond Res Publish Ahead of Print. doi: 10.1519/JSC.0000000000002742
32. Weakley JJS, Wilson KM, Till K, Read DB, Darrall-Jones J, Roe GA, Phibbs PJ, Jones BL (2019d) Visual feedback attenuates mean concentric barbell velocity loss, and improves motivation, competitiveness, and perceived workload in male adolescent athletes. J Strength Cond Res 33:2420-2425. doi: 10.1519/JSC.0000000000002133
33. Wilson KM, Helton WS, de Joux NR, Head JR, Weakley JJ (2017) Real-time quantitative performance feedback during strength exercise improves motivation, competitiveness, mood, and performance. Proc Hum Factors Ergon Soc Annu Meet 61:1546-1550. doi: 10.1177/1541931213601750
34. Wilson KM, De Joux NR, Head JR, Helton WS, Dang J, Weakley J. Presenting objective visual performance feedback over multiple sets of resistance exercise improves motivation, competitiveness, and performance. Proc Hum Factors Ergon Soc Annu Meet 62:1306-1310. doi: 10.1177/1541931218621299