The effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics during the barbell back squat

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ABSTRACT

Purpose: Prescribing resistance training using velocity loss thresholds can enhance exercise quality by mitigating neuromuscular fatigue. Since little is known regarding performance during these protocols, we aimed to assess the effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics in the free-weight back squat.

Methods: Using a randomised crossover design, sixteen resistance-trained men were recruited to complete five sets of the barbell back squat. Lifting load corresponded to a mean concentric velocity (MV) of ~0.70 $m \cdot s^{-1}$ (115 ±22kg). Repetitions were performed until a 10%, 20% or 30% MV loss was attained.

Results: Set MV and power output were substantially higher in the 10% protocol (0.66 $m.s^{-1}$ & 1341 W, respectively), followed by the 20% (0.62 & 1246) and 30% protocols (0.59 & 1179). There were no substantial changes in MV (-0.01– -0.02) or power output (-14– -55 W) across the five sets for all protocols and individual differences in these changes were typically trivial to small. Mean set repetitions were substantially higher in the 30% protocol (7.8), followed by the 20% (6.4) and 10% protocols (4.2). There were small to moderate reductions in repetitions across the five sets during all protocols (-39%, -31%, -19%, respectively) and individual differences in these changes were small to very large.

Conclusions: Velocity training prescription maintains kinetic and kinematic output across multiple sets of the back squat, with repetition ranges being highly variable. Our findings therefore challenge traditional resistance training paradigms (repetition-based) and add support to a velocity-based approach.

Key words: Velocity-based training; velocity; power; resistance training

INTRODUCTION

Velocity-based training (VBT) is a contemporary method of resistance training that accounts for fluctuations in physical characteristics, and daily readiness [1,2]. Additionally, implementing VBT can enable practitioners to accurately prescribe velocity loss thresholds (e.g. a 10% velocity loss threshold) that targets specific kinetic and kinematic outputs [3-5]. Velocity loss thresholds are calculated from the maximal attainable velocity output during a training session, which is typically determined from the initial repetition of the first training set, and can guide the practitioner when to terminate a training set [6]. For example, a 10% velocity loss threshold with an initial repetition speed of 0.70 $m \cdot s^{-1}$ would require an individual to terminate the set when the repetition velocity dropped below 0.63 $m \cdot s^{-1}$. The application of thresholds help guide practitioners to understand the magnitude of velocity loss and neuromuscular fatigue that has occurred [5,7].

The application of velocity loss thresholds are commonly used to prescribe training volumes due to their influence on both structural and functional muscle adaptations [3,4,8]. Larger velocity loss thresholds (e.g. 30% *vs*. 10%) have been demonstrated to promote greater hypertrophic adaptations due to the increased training volume that can be achieved prior to set termination [4]. Alternatively, smaller thresholds (e.g. 10% vs. 30%) encourage greater development of strength and power due to reduced neuromuscular fatigue and preferential hypertrophy of type II fibers [3,4]. However, little is known about the kinetic and kinematic outputs that underpin this form of resistance training prescription. Additionally, the expected range of repetitions that can be completed within a training session has not been detailed.

Recent studies have used 10%, 20%, and 30% velocity loss thresholds during VBT prescription [6,9,10]. However, previous research has suggested that divergent training adaptations occur when these differing thresholds are applied [3,4]. Furthermore, the number of repetitions that can be completed within a given velocity loss threshold has been suggested to be highly variable depending upon the number of sets completed and the individual involved [4,10]. But the extent of this interindividual variability is yet to be formally quantified. We therefore aimed to describe the within- and between-condition differences in kinetic, kinematic and repetition characteristics of 10%, 20%, and 30%, and to determine the interindividual variability of these differences.

METHODS

Design

We utilised a counterbalanced crossover design to assess the effects of different velocity loss thresholds on kinetic, kinematic, and repetition data during the barbell back squat. Eighteen team sport athletes volunteered to complete the three resistance training protocols, with two athletes being lost to follow up. Following a familiarisation session, athletes completed a 10%, 20%, and 30% velocity loss condition that was based upon an initial mean concentric velocity of 0.70 ± 0.01 $m \cdot s^{-1}$. Testing occasions consisted of five sets of the back squat (interspersed with three minutes recovery), with the external load in set one being adjusted so that the mean concentric velocity of the fastest repetition of the final warm-up set was 0.70 ± 0.01 $m \cdot s^{-1}$. In sets 2-5, the initial repetition velocity was required to be 0.70 ± 0.06 $m \cdot s^{-1}$ [11].

Subjects

Sixteen male team sport athletes (mean ± standard deviation [SD]; age: 23.1 ± 2.4 years; body mass: 88.8 ± 13.3 kg; height: 180 ± 7 cm) from a British University and Colleges Super Rugby club (United Kingdom) completed our study. All athletes had at least two years resistance training experience with the back squat exercise [12], had been completing a resistance training programme for the previous six months that involved intensities between 60-93% of one repetition maximum (1RM), and had been habitually completing this exercise at least twice a week for three months without interruption. The testing took place during the off-season period of the rugby union playing calendar. During the familiarisation session, athletes were explained the design of the study, given the opportunity to ask questions, and then provided written consent. Athletes then demonstrated the back squat exercise to ensure the strict technique requirements of the study were adhered to. All experimental procedures were approved by the Leeds Beckett University's ethics committee.

Methodology

Resistance training sessions

Following familiarisation, athletes were assigned to three testing occasions separated by at least 72 hours. All occasions were at the same time of day and required athletes to have not completed any strenuous exercise for the preceding 48 hours. For each occasion, athletes completed a warm-up which consisted of dynamic movements [13]. Following this, a squat specific warm-up was completed which consisted of eight repetitions with an empty barbell (Eleiko Sport AB, Halmstad, Sweden), followed by three sets of 3-5 repetitions at self-selected submaximal loads [12,14,15]. During the warm-up, the mean concentric velocity of all repetitions was monitored by a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) [16,17].

After 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. 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. This velocity was chosen as it is similar to the initial velocity in previous VBT research [9] and has demonstrated satisfactory between-day reliability [11]. Adjustments were made according to previous research by Banyard et al. [9]. Briefly, if mean concentric velocity was 0.06 $m \cdot s^{-1}$ higher or lower than 0.70 $m \cdot s^{-1}$, the external load was adjusted by ±5% of estimated 1RM [9]. 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 velocity of 0.70 ± 0.01 $m \cdot s^{-1}$ was found, subjects 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 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. In sets 2-5, the initial repetition of the set was required to be 0.70 ± 0.06 $m \cdot s^{-1}$. This was based on extensive piloting prior to the initiation of the study that found that the smallest detectable difference (normal variation in velocity) in mean concentric velocity between sets was 0.06 $m \cdot s^{-1}$. This agrees with previous research that has shown that the smallest detectable difference between sessions with relative loads ranging from 20%1RM to 80%1RM is also ±0.06 $m \cdot s^{-1}$ [11]. 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 barbell velocity 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.

Outcome measures

A linear position transducer was used to collect all data within this study. The linear position transducer used a variable rate sampling method with level crossing detection that assisted in the interpretation of data points. The encoder provides approximately one electrical impulse every three millimetres of barbell displacement with each value time stamped with a one-millisecond resolution. This "down samples" to a maximum of 50 samples per second (i.e. 50Hz). This method is utilised as it means the transducer adapts to the rate of change and removes noise associated with high frequency sampling as data is only recorded during movement. This information was then transmitted via Bluetooth^{TM} to a tablet (iPad, Apple Inc., California, USA). The retractable cord was placed at the furthest position of the grip section of the barbell for all trials (i.e. approximately 65cm from the centre of the bar) [18], with the linear position transducer demonstrating acceptable levels of validity and reliability for velocity, power, and force [19, 20]. Mean and peak concentric kinetic and kinematic outputs were averaged for each of the five sets during the 10%, 20%, and 30% velocity loss threshold conditions and used for further analysis.

Statistical analyses

Raw load, kinetic and kinematic data were seen to be plausibly normally distributed for each set and are presented as the mean ± standard deviation (SD). Counts of repetitions were positively skewed and are summarized using the mode, median, interquartile range and total range. Repetition counts were also log-transformed prior to analysis and subsequently back transformed post-analysis, with the resultant effect statistics given as accurate percentages.

We used linear mixed effect models (SPSS version 24, IBM, Armonk, NY, US) to compare kinetic, kinematic and repetition data within and between each 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 also specified as a fixed effect (factor, with intercept) and was interacted with sets to compare the typical (mean) set performance between each condition (i.e. difference in intercepts) and differences in the linearized rate of change in each outcome measure over the 5 sets. Models were also fit with a random intercept for athlete and a random slope for set, using an unstructured covariance matrix, to quantify individual differences (as SDs) in the linearized change across the five sets.

Uncertainty in all outcome measures was expressed with 90% confidence intervals (CI). We used non-clinical magnitude-based inferences [21,22] to provide an interpretation of the size and uncertainty of all effects. The between-athlete SD was multiplied by thresholds of 0.2, 0.6, 1.2, and 2.0 anchor small, moderate, large, and very large effects, respectively [21]. Since we employed tightly controlled velocity loss protocols, between-player SDs for mean and peak velocity were artificially small and deemed inappropriate to anchor changes and differences.

Instead, we used between-player SDs of 0.09 for mean velocity and 0.17 $m \cdot s^{-1}$ for peak velocity, which have been previously reported by Banyard and colleagues [11] in resistance trained men performing the barbell back squat at comparable intensities to the athletes in our study (60–80% 1RM). The likelihood of the true effect being the observed magnitude or trivial was interpreted using a scale of probability descriptors [21]. Standard deviations representing individual differences in the linearized change across the five sets were doubled before interpreting their magnitude above these thresholds.

RESULTS:

Descriptive data

The mean (± SD) external loads for 10%, 20% and 30% protocols were 116.1 (± 21.9) kg, 113.9 (± 21.5) kg, and 114.9 (± 21.5) kg. Descriptive data for kinetic and kinematic outcomes are presented in Figure 1 and descriptive data for repetitions are presented in Table 1.

*****Insert Figure 1 and Table 1 here*****

Comparison of kinetic and kinematic outcomes

Mean and peak set velocity were likely to most likely lower during the 20% protocol (small magnitudes) and 30% protocol (moderate magnitudes) when compared with the 10% protocol, with the 30% protocol also being most likely lower than the 20% protocol (small magnitudes). There was no substantial difference in mean or peak set force between protocols (Table 2). Mean and peak set power was very to most likely lower during the 20% protocol (small magnitudes) and 30% protocol (moderate and small magnitudes, respectively) when compared with the 10% protocol (Table 2). When comparing the 30% protocol with the 20% protocol, mean power was most likely lower (small magnitude) and peak power was possibly lower (small magnitude)/possibly the same (trivial; Table 2).

*****Insert Table 2 here*****

The change in mean and peak kinetic and kinematic variables across the five sets were possibly to most likely trivial for each protocol (Table 3 & 4), except for mean set power for the 30% condition, which likely reduced by a small magnitude (Table 3). Individual differences in these changes (represented as SDs in Table 3 and 4) were trivial to small for all variables, with the exceptions of mean velocity and power for 10%, which were moderate.

*****Insert Table 3 here*****

*****Insert Table 4 here*****

Comparison of repetitions

Players performed most likely more repetitions during the 20% protocol (moderate magnitude) and very likely more reps during the 30% protocol (large magnitude) when compared with the 10% protocol (Table 5); with very likely more repetitions completed during the 30% protocol when compared with the 20% protocol (small magnitude). There were possibly and very likely small reductions in repetitions across the five sets for the 10% and 20% protocols, with the reduction during the 30% protocol being possibly moderate (almost certainly small; Table 5). Individual differences in these changes (represented as SDs in Table 5) were very large for 10%, small for 20%, and moderate for 30%.

*****Insert Table 5 here*****

DISCUSSION:

Prescribing resistance training using velocity loss thresholds can enhance exercise quality by mitigating neuromuscular fatigue. Since little is known regarding performance during these protocols, we aimed to assess the effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics in the squat. Our findings show that velocity loss prescription can mitigate the loss of kinetic and kinematic outputs across 5 sets of the barbell back squat, with typically trivial to small changes evident and individual differences in these changes being typically trivial to small (i.e. consistent). By comparison, the number of repetitions completed in each set substantially reduced and individual differences in these changes were small to very large (i.e. inconsistent). Finally, we observed greater kinetic and kinematic outputs with smaller velocity loss thresholds (i.e. 10% > 20% >30%), whilst larger thresholds enabled a greater number of repetitions to be completed. Collectively, our findings suggest that velocity loss thresholds are of importance when aiming to maintain set ’quality’, as athletes have differing strength endurance characteristics. These data therefore challenge traditional resistance training paradigms (e.g. repetition-based prescription) and add support to a velocity-based approach.

By utilising velocity loss thresholds, we found that both mean and peak velocity and power could be maintained across each set (Figure 1), with typically trivial to small differences between athletes (Tables 3 and 4). Additionally, we observed substantially greater mean and peak barbell velocities when smaller velocity loss thresholds were applied when compared to larger thresholds. This agrees with previous research that has shown that greater velocity loss thresholds can reduce kinetic and kinematic outputs [3]. This is of importance for athletes as greater losses in training velocities have been demonstrated to impair adaptations (e.g. 1RM strength and jump height) [3,4,8]. Consequently, these findings support the tenet that more accurate monitoring can transpire when sets are terminated at pre-determined cut-off velocities. By utilising these velocity loss thresholds, losses in velocity and power that are often observed across multiple sets can be negated [23]. Therefore, due to the attenuated reduction and between set consistency of kinematic outputs by utilising velocity loss thresholds, we recommend that practitioners consider monitoring resistance training intensities and volumes with this method.

While we found substantial between condition differences in velocity and power outputs, the differences across sets and between protocols in mean and peak force were trivial. This is the first study to highlight the lack of difference in this variable when utilising differing velocity loss thresholds and may be explained by the consistencies in bar load (weight) in every protocol, coupled with the stable nature of force production when completing the barbell back-squat [24]. This agrees with previous findings that have shown that changes in external load, rather than accumulating neuromuscular fatigue during exercise, have the greatest influence on this kinetic variable [23]. This should be noted by the practitioner as it suggests that despite substantial decreases in velocity and power during exercise, force variables remain relatively stable. Therefore, force variables are not advised to be used to monitor changes in neuromuscular function during resistance training.

Another important finding from our study was the inter-individual variability that was observed in the change of repetitions across the five sets (Table 5). The small to very large SDs—

representing individual differences in the ‘linearized’ reduction of repetitions over the five sets— suggest that individuals have differing rates of fatigue in response to velocity loss protocols. This is despite additional rest (30 seconds) and changes in external load (~5% of 1RM) being allowed when athletes were unable to reach the initial starting velocity of a set. Such a finding supports the notion that traditional methods of prescribing resistance training (e.g. repetition-based from a percentage of 1RM) are unable to maintain kinetic and kinematic outputs across sets [23] and may cause athletes to have substantially differing neuromuscular fatigue responses when completing the same training session. Therefore, we strongly recommend that, rather than prescribe set repetition schemes (e.g. 10 repetitions across all sets with a specified percentage of 1RM), appropriately prescribed relative losses in mean concentric velocity are used. This approach allows practitioners to have greater control of neuromuscular fatigue, improved ability to account for interindividual differences in recovery between repeated bouts of exercise, and ensure that repetition quality is maintained.

Finally, due to the larger velocity loss permitted, larger velocity loss thresholds allowed for greater number of repetitions to be completed (i.e. 30%>20%>10%). However, as shown by the range of repetitions within conditions (Table 1), substantial deviation around the median repetition number did occur. This demonstrates varying rates of barbell velocity loss during exercise (e.g. a rapid loss in velocity versus a gradual decline) and supports previous research that has demonstrated athletes may need to perform a varying number of repetitions prior to achieving a given percentage of velocity loss [25]. This could be explained by training history and/or differing levels of muscular endurance [4]. Despite this, the greater training volumes but lower overall kinematic outputs observed in the 20% and 30% conditions might affect subsequent adaptations when adhering to these protocols over time [4,7]. Larger velocity loss thresholds can attenuate strength and power adaptations but induce greater muscle hypertrophy

[3,4,7]. Therefore, larger velocity loss thresholds (e.g. 30%) may be used to increase training volume but ensure that concentric failure is not reached. Alternatively, smaller velocity loss thresholds (e.g. 10%) can be implemented to ensure greater kinematic outputs and mitigate the accumulation of neuromuscular fatigue [4,7].

While this study improves the knowledge of VBT and the implementation of velocity loss thresholds, it is not without limitations. We acknowledge that differing initial starting velocities (e.g. $0.40 \text{m}\cdot\text{s}^{-1}$ vs. $0.70 \text{m}\cdot\text{s}^{-1}$) may alter the number of repetitions and kinetic and kinematic outputs within a training set [3,25]. Despite this, previous evidence suggests that velocity loss thresholds continue to follow similar trends with different starting velocities (e.g. greater velocity loss thresholds cause increases in the number of repetitions and increased loss of kinematic outputs) [3,4,25]. In addition, while our data further the understanding of the performance-based responses to velocity loss protocols, knowledge of the associated internal responses are still tenuous. Research has shown that as velocity loss occurs, alterations in metabolic (e.g. lactate) and neuromuscular (e.g. countermovement jump) function transpire [5]. However, these responses have not been quantified using commonly implemented velocity loss thresholds. Since the internal response to training drives both positive (e.g. adaptation/fitness) and negative (fatigue/overtraining) outcomes, future research is warranted to examine the effects of these thresholds on perceptual, metabolic, and neuromuscular function to gain a better understanding of training prescription.

PRACTICAL APPLICATIONS

We recommend that relative velocity loss is used to inform practitioners when set termination should occur. By applying relative velocity loss thresholds, the accrual of fatigue throughout a workout and individual differences in work capacity can be accounted for which enables the maintenance of kinetic and kinematic outputs across multiple sets. Additionally, differing velocity loss thresholds can alter the kinetic and kinematic outputs, and total volumes that can occur. For example, a 10% threshold may typically achieve an average set peak power output of >3000 W through a range of 2–11 repetitions, whereas a 30% protocol may achieve a most likely lower mean peak power (i.e. <3000W) through a possible range of 3–24 repetitions. Consequently, we recommend that practitioners utilise smaller velocity loss thresholds (e.g. 10 and 20%) when aiming to maximise kinematic outputs and reduce neuromuscular fatigue responses during training. This may be useful during strength and power mesocycles, or when fatigue is undesirable (e.g. close to competition). Alternatively, when aiming to increase training volumes but avoid concentric failure, larger velocity loss thresholds (e.g. 30%) should be used. This may be more favourable for the development of muscular hypertrophy.

CONCLUSIONS

In conclusion, velocity loss thresholds are a valid method of monitoring resistance training. By applying 10%, 20%, and 30% thresholds during the back squat, improved prescription of kinetic and kinematic outputs can be achieved while minimising the large amount of within- and between-athlete variability in both velocity and power that occurs when prescribing from traditional methods (i.e. a number of repetitions and sets at a percentage of maximal ability). This supports previous research [23] showing traditional methods of resistance training cause reduced kinematic outputs, particularly in latter training sets, which may be detrimental to strength, power, and physical performance adaptations. Consequently, practitioners should consider applying velocity loss thresholds when resistance training to: 1) accurately monitor and prescribe resistance training loads; 2) achieve pre-determined levels of neuromuscular fatigue across multiple sets; and 3) ensure that repetitions are completed with appropriate levels of velocity and power and mitigate the effects of accrued fatigue from previous sets.

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Figure 1. Average mean and peak concentric kinetic and kinematic outputs across five sets in the 10, 20, and 30% velocity loss threshold conditions. The mean change in m·s^{-1}, W, and N from the first to the fifth set is also shown. (**A**) Average mean velocity (m·s^{-1}); (**B**) Average peak velocity (m·s^{-1}); (**C**) Average mean power (W); (**D**) Average peak power (W); (**E**) Average mean force (N); (**F**) Average peak force (N).

Table 1. Descriptive repetition data of the 10, 20, and 30% velocity loss conditions.

Table 2. Comparison of mean set kinematic, kinetic and repetition performance across the three velocity loss protocols.

Table 3. Changes in mean concentric kinetic and kinematic performance across the five sets for each protocol.

Table 4. Changes in peak concentric kinetic and kinematic performance across the five sets for each protocol.

Table 5. Changes in repetitions across the five sets for each protocol.