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Time Course Changes in Maximal Strength and Velocity Following a Traditional Strength- or Power-Orientated Training Session

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Statement of Original Contribution

This thesis is the candidate's own work and contains no material which has been accepted for the award of any degree or diploma in any other institution.

To the best of the candidate's knowledge, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Alexander Vernon	26/03/2019
Candidate's name	Date

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Abstract

The primary aim of this study was to investigate the return to baseline of movement velocity and maximal strength following a typical strength-orientated and power-orientated session in the full depth, free-weight back squat performed with maximal concentric velocity. Fourteen strength-trained males completed a power-orientated session (3-sets of 6-repetitions @50% of a one-repetition maximum [1RM]) and a strength-orientated session (5-sets of 5-repetitions @80%1RM) in randomised order over two weeks. At 24, 48, 72 and 96-hours following the training session stimulus, sessions were completed with loads of 20%, 40%, 60%, 80%, 90% and 100%1RM lifted. Prior to the completion of the training sessions, individualised baseline load-velocity profiles were conducted based on the relative loads 20%, 40%, 60%, 80% and 90%1RM. Paired sample T-tests and effect sizes (ES) using Cohen's D reported differences in mean velocity (MV), peak velocity (PV) and peak force for each relative load at baseline and each time point for all participants. 1RM was also compared between baseline and each time point. Large (≥0.80) and medium (0.50 to 0.79) ES were reported for MV and PV at loads of 60% and above until 72h after the strength-orientated training protocol. Small (0.20 to 0.49) to trivial (<0.20) ES were reported for velocity in the days following the power-orientated training protocol. Similarly, only small to trivial changes in ES were observed for maximal strength and peak force at all relative loads and time points for both the strength and power-orientated training protocols. The results of the study suggest that return to baseline of MV and PV did not coincide with the return to baseline of maximal strength or peak force. Therefore, measuring meaningful changes in velocity may be a more practical monitoring tool to determine an individual's readiness to train.

Introduction

Resistance training is a common form of exercise implemented in clinical and athletic environments to improve muscle size, strength and power (Conlon et al., 2016). Training for specific outcomes is often prescribed by coaches manipulating training volume, load and frequency (Kraemer & Ratamess, 2004). To allow the prescription of training loads, 1-repetition maximum (1RM) assessments are often performed to determine individual submaximal loads. Importantly, coaches should monitor athletes to prevent injuries, facilitate optimal recovery, and to assess training targets (Joyce & Lewindon, 2014).

1RM assessments are used as a testing measure to periodically track maximal strength changes (Desgorces, Berthelot, Dietrich, & Testa, 2010). Additional strength assessments such as isometric assessments, countermovement jumps, and subjective physical exertion scales are also used to monitor athlete resistance training performance (Beckham et al., 2013; Day, McGuigan, Brice, & Foster, 2004; Gathercole, Sporer, Stellingwerff, & Sleivert, 2015). However, these assessments present certain limitations and cannot be accurately used to prescribe training volume and loads to accommodate for daily fluctuations in performance.

Recent progress in the research of velocity-based training (VBT) has identified useful benefits for the monitoring of resistance training, using movement velocity. As such, measuring the velocity of an exercise can ensure athletes are lifting with maximal concentric effort to greatly improve strength and power adaptations compared to self-selected intensities (Padulo, Mignogna, Mignardi, Tonni, & D'ottavio, 2012). Furthermore, decreases in movement velocity are related to physiological markers of fatigue, which may suggest VBT can determine an individual's daily readiness to train (Sánchez-Medina & González-Badillo, 2011). To determine appropriate training velocities or the effect of fatigue on an individual it is first important to measure baseline velocity values. Baseline values are established using load-velocity profiles (LVP) which determine individualised velocities for specific relative loads (Banyard, Nosaka, Vernon, & Haff, 2018; Banyard, Tufano, Delgado, Thompson & Nosaka, 2019).

The relationship between load and velocity is vital in understanding the influence of fatigue during VBT. Importantly, when maximal effort is given for the concentric (upward) phase of an exercise, an inverse linear relationship exists between movement velocity and load (Sánchez-Medina, Perez, & González-Badillo, 2010). Studies have also reported that when an athlete begins to fatigue within a training set, their movement velocity declines (Izquierdo et al., 2006; Sánchez-Medina & González-Badillo, 2011), suggesting that concentric muscular force production declines as fatigue ensues. Furthermore, it has recently been shown that movement velocity at sub-maximal loads is reliable between training sessions if an individual is in a non-fatigued state (Banyard et al., 2018). Consequently, if an athlete's movement velocity is slower than their baseline LVP, their training load could be adjusted to avoid prolonged fatigue, which cannot be applied using 1RM assessments.

Despite numerous studies that have researched VBT, much of the research has been based on individuals in non-fatigued states (González-Badillo & Sánchez-Medina, 2010; Conceição, Fernandes, Lewis, González-Badillo, & Jimenéz-Reyes, 2016; Banyard et al., 2018). Currently, there is a lack of research explicitly investigating the effect of fatigue on velocity following resistance training sessions. The primary aim of this study was to quantify the time-course changes in movement velocity following a typical maximal strength-orientated, and power-orientated resistance training session for the back-squat exercise. Secondly, the study aimed to determine the rate in which maximal strength returns following the maximal strength-orientated, and power-orientated resistance training sessions, performed in a randomised order. Exploring this aspect of training may provide coaches with an accurate method for adjusting training loads to enhance recovery and ensure desired adaptations are being targeted.

Purpose of the study

Previous research has investigated the effects of resistance training on movement velocity. Izquierdo et al. (2006) established that movement velocity decreases as an individual becomes fatigued within a resistance training session. However, it is not yet known what happens to movement velocity in subsequent days following resistance training, when an athlete is under the influence of fatigue during recovery. The purpose of this study was to determine when an individual's movement velocity and maximal strength returns to baseline levels following resistance training and to establish if movement velocity is a better indicator of training readiness than current maximal strength methods.

Significance of the study

This study will complement the current literature regarding the effects of resistance training on movement velocity. Previous research has established movement velocity declines as a result of cumulative sets of resistance training exercises however, the nature of potential movement velocity declines in ensuing days has not be investigated (Izquierdo et al., 2006; Sánchez-Medina & González-Badillo, 2011). The results of this study may provide coaches with the knowledge of when an individual's movement velocity returns to baseline levels following specific resistance training protocols. Based on these results, coaches may be provided with more accurate feedback regarding the readiness of an individual to train. Therefore, prescription of resistance training sessions can be modified to consider daily fluctuations in performance and more precise periodisation of training may maximise adaptations and prevent overtraining.

Research Questions and Hypothesis

The major research questions of this proposed study are:

1. Does movement velocity (MV and PV) decrease at 20, 40, 60, 80, 90 and 100% of 1RM at 24, 48, 72, and 96hrs after a typical power and maximal strength-orientated resistance training session for the back-squat exercise?

Null H1 – MV and PV will not decline in the days following the training sessions.

Alternate H1 – MV and PV will decline in the days following the training sessions.

2. Will maximal strength decrease following a typical power-orientated and maximal strength-orientated resistance training protocol for the back-squat exercise?

Null H1 – Maximal strength will not decline in the days following the training sessions.

Alternate H1 – Maximal strength will decline in the days following the training sessions.

Limitations

The research has been conducted on a homogeneous resistance training group, however even though the participants were well trained and had similar relative strength to their body mass (1.7 x body mass), there was some variability in their resistance training background. For example, some of the participants were power lifters and lift with very heavy loads on a regular basis. Thus, they were able to recover their maximal strength rapidly following a typical heavy strength-orientated training session.

The findings of this study are limited to well-trained participants. Therefore, these results may not be applicable to novice lifters. Additionally, these findings may not be applicable to resistance training exercises, other than the free-weight back squat. Also, considering only the free-weight back squat exercise was used for the study, it may not truly reflect the output during a resistance training program in an athletic setting where multiple exercises are completed within a session.

Delimitations

Only healthy participants with at least 6 months of resistance training experience and the ability to back-squat 1.5 times their bodyweight took part in the study. Additionally, only the back-squat exercise was used for the study and all repetitions were monitored by qualified researchers to ensure consistent squat performance was achieved. Individual testing session times were strictly kept the same for each session. Lastly, wellness questionnaires were not given to participants to complete. External factors such as sleep, or nutrition may have provided an explanation for certain results.

Review of the Literature

Resistance training exercise can be used to increase the size, strength, and power of skeletal muscle in both clinical and athletic settings (Conlon et al., 2016; Randell, Cronin, Keogh, Gill, & Pedersen, 2011). To elicit specific muscular adaptions, resistance training protocols are manipulated by controlling certain training variables. These variables include but are not limited to, training volume (amount of repetitions and sets), frequency (number of training sessions) and training load (weight lifted) (Kraemer & Ratamess, 2004). Resistance training loads are often prescribed as submaximal loads relative to the results of a 1RM. The 1RM is a valid and reliable assessment of maximal strength for a specific exercise (Levinger, 2007) but its regular use as a monitoring tool is problematic. For example, the 1RM assessment is time consuming, particularly when testing large groups of athletes (Desgorces et al., 2010). Furthermore, the risk of injury may be increased during 1RM testing when lifting with heavier loads, and there is the potential for variation in test results with untrained individuals who are not accustomed to 1RM testing (Hoeger, Hopkins, Barette, & Hale, 1990; Symons, Vandervoort, Rice, & Overend, 2005). A further complication with prescribing resistance training loads from a pre-determined 1RM assessment is that maximal strength may fluctuate due to daily variations in an individual's performance (Mann, Kirk, Brick, & Patrick, 2016). Therefore, it is necessary to establish a less demanding method of regularly monitoring an athlete's training performance. This may then allow coaches to modify and individualise training where necessary.

Several strength assessments have been developed to monitor athletic performance. For example, the isometric mid-thigh pull assessment is commonly used for strength assessment and fatigue monitoring where a coach can monitor changes in peak force, among other variables (Beckham et al., 2013). Alternatively, the measurement of velocity and force output for the CMJ has also been used to monitor the training performance of athletes (Gathercole et al., 2015). Although the CMJ and isometric strength assessments are valid and reliable for athlete monitoring, they do not precisely define how training load or training volume can be modified for specific exercises. Therefore, it would be hugely beneficial for strength coaches to establish a monitoring method that can assess fluctuations in day-to-day performance and individualise training for specific exercises.

Due to the advancement of kinetic technologies, recent research has explored the monitoring of velocity during resistance training, which has led to the advancement of velocity-based training (VBT) methods. Utilising these methods provides several benefits. First, velocity is important for determining the level of intensity and adaptation in training. For example, training with maximal intended velocity throughout the concentric (muscle shortening) phase of a lift will lead to greater enhancement of maximal strength and power compared to self-selected (Padulo et al., 2012), or intentionally slower concentric muscle contractions (González-Badillo, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & Pareja-Blanco, 2014). Second, decreases in velocity are highly correlated with physiological markers of fatigue (Sánchez-Medina & González-Badillo, 2011). This suggests that monitoring fluctuations in velocity during training can help identify the magnitude of fatigue for a specific exercise and an individual's day-to-day performance. Third, an almost perfect inverse linear relationship exists between the resistance training load and velocity (load-velocity relationship) (González-Badillo & Sánchez-Medina, 2010). This suggests that it is possible to monitor an athlete's velocity for a specific exercise by using their individualised load-velocity profile to ensure that desired velocity targets are achieved (Balsalobre-Fernández, García-Ramos, & Jiménez-Reyes, 2018; Pestaña-Melero, Haff, Rojas, Pérez-Castilla, & García-Ramos, 2018). Therefore, it appears that monitoring velocity can better inform training-based decisions to optimise training. The objective of this review of literature is to discuss the importance of VBT methods to determine an individual's readiness to train and examine the limitations of current research which guide the direction of this thesis.

Strength and Power Training

Resistance training programs are often designed to focus on specific training adaptations to improve an individual's athletic performance. Strength or power-orientated training can enhance explosive movements such as running and jumping (Hoffman, 2014, pp. 131-133). It is recommended that individuals targeting increases in strength or power should train with a high rate of force development and with the fastest attainable velocity in order to preferentially activate type II muscle fibres required for the movement demands of their given sport (Haff & Triplett, 2016). Research suggests that optimal power training loads are often prescribed by lifting light to moderate loads of 30-70% 1RM (Soriano, Jiménez-Reyes, Rhea, & Marín, 2015) with 1-5 repetitions for 3-5 sets and rest periods of 2-5 minutes between sets (Haff & Triplett, 2016)). By comparison, maximal strength adaptations can be optimised by lifting loads of ≥80% 1RM (Cormie, McGuigan, & Newton, 2011) for sets of 2-6 for 6 or less repetitions with 2-5 minutes of rest between sets (Haff & Triplett, 2016).

During resistance training exercise, the phosphagen system in the body is the principal energy system involved in the performance of explosive movements which are desired to increase an individual's strength and power output (Haff & Triplett, 2016). The phosphagen system only lasts for up to 10 seconds of maximal effort and once exhausted, there is a rapid decrease in the ability to produce movement velocity (Cardinale, Newton, & Nosaka, 2011, pp. 71-80). If energy stores are exhausted without adequate recovery, aiming to produce maximum movement velocity in an energy depleted state could result in adaptations to slower and higher fatigue resistant muscle fibres. This is critical for individuals who are predominately targeting explosive force production. Furthermore, to enhance strength and power development, resistance training should be prescribed to sustain the highest possible velocity output against a given load whilst minimising the amount of movement velocity lost within a session. In turn, this will stimulate the required energy system and target the Type II muscle fibres which are primarily responsible in maximising strength and power development (Jeffreys & Moody, 2016, pp. 308-310). Therefore, monitoring velocity during resistance training can help limit the number of repetitions performed with undesirable velocity outputs.

Measuring Movement Velocity

Linear position transducers (LPT) are a reliable and valid tool commonly utilised by strength coaches to quantify movement velocity (Banyard, Nosaka, Sato, & Haff, 2017; Cronin, Hing, & McNair, 2004; Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007; Hansen, Cronin, & Newton, 2011). The device consists of a retractable tether connected to a spring-loaded reel that is coupled with a rotational sensor (encoder or potentiometer) (Harris, Cronin, Taylor, Boris, & Sheppard, 2010). As the retractable tether is lengthened or shortened by the object it is attached to (i.e. barbell), the rotational encoder generates a signal relative to the displacement of the barbell and the time taken for the movement, and thus velocity is derived. This feedback is inclusive of specific velocity variables observed through both the concentric and eccentric phases of a movement (i.e. mean and peak velocity) (Harris et al., 2010).

One benefit of using an LPT to measure movement velocity in resistance training exercises is to ensure that an athlete is providing maximal effort for every repetition, which can lead to greater training adaptations over time (González-Badillo et al., 2014). Randell et al. (2011) had 13 professional rugby league players train for 6 weeks with 7 participants receiving instantaneous repetition feedback regarding peak velocity for their performance while the other 6 participants did not. Training involved 3 standardised pre-season conditioning sessions a week. Two of the 3 weekly sessions required players to perform 3 sets of 3 concentric squat jumps with a 40kg barbell. Following the training intervention, the feedback group had a 1.8% superior increase in vertical jump height compared to the non-feedback group. This suggests a coaches' ability to provide quantitative feedback using an LPT can improve an athlete's training output when repetitions are performed with maximal effort.

When measuring velocity using an LPT, three concentric velocities are commonly measured, which include peak concentric velocity (PV), mean concentric velocity (MV), and mean propulsive velocity (MPV). PV is strongly associated with performance during ballistic type resistance training movements however, it has been suggested that MV is a more relevant measure for non-aerial movements (Jidovtseff, Harris, Crielaard, & Cronin, 2011). MV represents the average of the velocity data completed during the entire concentric phase of a movement (Jidovtseff et al., 2011; Sánchez-Medina & González-Badillo, 2011). A study by Sanchez-Medina and González (2011) established MV of the squat and bench press exercises using light loads might underestimate the individual's performance capacity. Lifting lighter loads resulted in the individual needing to decelerate the barbell at the end of a movement to maintain balance and to avoid continued acceleration through "jumping" or "throwing" actions. To avoid this limitation, MPV was developed which is the average concentric velocity data of a movement during the time periods when the object being lifted was accelerating at a greater speed then acceleration due to gravity (-9.81 $m \cdot s^{-2}$). The measurement of MPV has been assessed in several studies (González-Badillo, Marques, & Sánchez-Medina, 2011; González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina & González-Badillo, 2011). Recently, PV, MV and MPV have been shown to be reliable between 20 and 90%1RM for the back squat, seated smith machine military press, smith machine bench press, and bench throw (Balsalobre-Fernández et al., 2018; Banyard et al., 2018; García-Ramos, Pestaña-Melero, Pérez-Castilla, Rojas, & Haff, 2018). These aforementioned reliability studies were performed on individuals in a rested state. However, to our knowledge, no studies have reported velocity measures when individuals are fatigued in the days following resistance training sessions. This is important to discern to enable strength and conditioning practitioners to determine the most effective time to commence training with appropriate training loads.

Incorporating the measurement of movement velocity for a target exercise during a given strength training session may prevent the need for alternative assessments. Additionally, using movement velocity to assess readiness to train could provide an objective measurement which is specific to fundamental exercises used during resistance training. Considering movement velocity has proved to be reliable it could be appropriate to use warm-up sets for the free-weight back squat as a fatigue assessment of the lower body, if consistent depth is maintained for every repetition and maximal concentric effort is given. If so, it will eliminate the need for additional testing sessions where time is often limited within an athlete's program. Furthermore, LPTs used to measure movement velocity are relatively inexpensive when compared with other monitoring tools such as in-ground, or portable force plates. Therefore, the modification of athlete training loads by measuring the movement velocity in the warm-up sets of an exercise and comparing to their LVP may decrease the requirement for additional fatigue monitoring assessments.

Load-Velocity Relationship

It is known that when an individual exerts maximal concentric effort with a consistent range of motion, a near perfect inverse linear relationship exists between load and velocity for a variety of exercises (González-Badillo & Sánchez-Medina, 2010). Thus, heavier loads cannot be lifted with the same velocity as lighter loads when maximal intended velocity is produced. Current research has investigated the load-velocity relationship using the Smith machine half squat (Conceição et al., 2016; Pérez-Castilla, García-Ramos, Padial, Morales-Artacho, & Feriche, 2018b), Smith machine concentric only half squat (Pérez-Castilla et al., 2018b), Smith machine full squat (Conceição et al., 2016), Smith machine CMJ (Pérez-Castilla et al., 2018b), Smith machine squat jump (Pérez-Castilla et al., 2018b), Smith machine bench press (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina, González-Badillo, Pérez, & Pallarés, 2014; Sanchez-Medina et al., 2010), Smith machine bench press throw (García-Ramos et al., 2018), Smith machine prone bench pull (Sánchez-Medina et al., 2014), Smith machine military press (Balsalobre-Fernández et al., 2018), free-weight deadlift (Lake et al., 2017), and pull up (Muñoz-López, Marchante, Cano-Ruiz, Chicharro, & Balsalobre-Fernández, 2017). Many of these studies have reported group mean equations for each exercise (Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011). However, recent research has suggested that individualised load-velocity profiles (LVP) should be created because different individuals produce unique movement velocities based on factors associated with their limb biomechanics, muscle fibre type expression and due to different sports requiring specific velocities and athletic capabilities. (Balsalobre-Fernández et al., 2018; García-Ramos et al., 2018; Pestaña-Melero et al., 2018).

The evidence from this research has allowed strength and conditioning coaches to profile their athletes for each exercise by creating individuals LVPs. The practical implications of this is that since it has been theorised that when an athlete is fatigued, the velocity of performed repetitions may decrease compared to their LVP which was established in a non-fatigued state. Alternatively, if an individual increases their maximal strength, it is assumed that velocity for the same absolute load will increase according to the load-velocity relationship. Importantly LVPs were established for individuals in a rested state, however it is not known what happens to LVPs when individuals are fatigued in the days following resistance training sessions.

Load-Velocity Profiles

The use of individualised LVPs may provide a valid measure of assessing fatigue. Importantly, the velocity of concentric muscle output decreases as force output increases from heavier loads (Cronin, McNair, & Marshall, 2003; González-Badillo & Sánchez-Medina, 2010). It is critical that LVPs are measured in non-fatigued states, as it may portray an unjust reflection of an individual's ability to lift maximally. Supposing a lift is performed with maximal concentric effort, if the velocity at submaximal loads does not match with the individual's velocity measured in their LVP which was established in a 'fresh' state, training sessions could be modified according to daily readiness. This is beneficial as training can be altered to avoid overtraining and exacerbated performance decreases.

A recent study has examined using LVPs as a method to monitor training (Banyard et al., 2018). Banyard et al. (2018) established the reliability of using peak velocity, mean propulsive velocity and mean velocity to create LVPs. 1RM trials were performed at six relative loads consisting of 20, 40, 60, 80, 90 and 100% 1RM. To quantify the relationship between relative load and velocity a linear regression was fitted to the data. By using this method, it was established that PV was highly reliable at all loads assessed. Furthermore, MPV and MV were highly reliable at every load except 100% 1RM due to the unstable nature of V_{1RM}. The high reliability this method of LVPs provides allows strength coaches to use this as a tool for monitoring loads for resistance training. Using this method, it is suggested a 1RM assessment is firstly conducted followed by an individualised LVP at the loads described previously. Consequently, training loads can be adjusted according to the smallest detectable difference of the individual athlete at the required training load. Whilst research has validated the use of LVPs in non-fatigued states, we are yet to understand what happens to movement velocity at each relative load when an athlete is fatigued.

1RM Predictions

To measure an athlete's maximal strength for a given exercise, a strength coach will commonly have their athlete perform a 1RM assessment. These assessments aim to measure the highest possible load an individual can lift for one repetition (Haff & Triplett, 2016, pp. 451-453). Once the 1RM load is determined, a coach can then prescribe resistance training loads to target a specific training adaptation. Periodic re-testing of 1RMs allows strength coaches to adjust loads to account for improvements in baseline maximal strength. A benefit of 1RM assessments is that they are simple to administer, as well as being valid and reliable (Haff & Triplett, 2016). However, they can also be problematic since additional testing sessions are required independent of regular training, which can be a time exhausting process when dealing with large groups of athletes (Symons et al., 2005; Urquhart, Moir, Graham, & Connaboy, 2015). Moreover, prescribing relative loads from a baseline 1RM assessment does not consider the effects of rapid increases in strength (week-to-week) and fatigue accrued by an individual who is not fully recovered. Interestingly, maximal strength has been shown to be very stable in a training week if an athlete is in a rested state (Banyard, Nosaka, & Haff, 2017). However, maximal strength is believed to fluctuate if an athlete is not fully recovered (return to baseline) in the subsequent days following strenuous exercise (Mann et al., 2016). Therefore, a more time efficient method to accurately assess maximal strength and prescribe training loads would be highly beneficial for practitioners.

The ability to accurately monitor movement velocity and provide immediate feedback has presented researchers with a novel method to predict 1RM from data collected with submaximal loads. Importantly, predicting 1RM from submaximal loads can estimate maximal dynamic strength, whilst eradicating the need to lift with maximal loads or perform submaximal repetitions to failure. A method of predicting 1RM is completed by extrapolating the load from the intersect of an individual's linear load-velocity regression line, and the velocity at 1RM (V_{1RM}) (Jovanović & Flanagan, 2014).

Recent research has indicated that the V_{1RM} 1RM prediction method ($1RM_{V1RM}$) can accurately predict the actual 1RM in the free-weight bench press (r = 0.99; CV = 0.82 – 1.48%), Smith machine bench press (r = 0.99; CV = 0.86 – 1.37%) and Smith machine half-squat exercise (r = 0.98; CV = 0.38 – 0.75%) (Loturco et al., 2017; Loturco et al., 2016). However, the accuracy of the $1RM_{V1RM}$ method to predict maximal strength in multi-joint compound exercises appears questionable. For example, a recent study by Ruf, Chéry, and Taylor (2018) determined that despite the high reliability of the $1RM_{V1RM}$ method (ICC = 0.95 – 0.99; CV = 1.9 – 4.4%; standard error of the measurement [SEM] = 3.4 – 7.5kg), it was not able to accurately predict the actual 1RM (r = 0.88 – 0.95; CV = 3.3 – 4.4%; SEE = 9.1 – 13.7kg) for the free-weight deadlift exercise due to the unstable V_{1RM} (ICC = 0.63; CV = 15.7%; SEM = 0.03 $m \cdot s^{-1}$). Similarly, Banyard et al. (2017) also found the $1RM_{V1RM}$ method had poor validity in the free-weight back squat due to the instability of V_{1RM} (ICC = 0.42; SEM = 0.05 $m \cdot s^{-1}$; CV = 22.5%; ES = 0.14). Thus, it appears that whilst high levels of accuracy have been established using the $1RM_{V1RM}$ method for Smith machine exercises and the free-weight bench press, this method offers differing results when applied to multi-joint compound free-weight exercises.

Importantly, accurate 1RM predictions using the $1RM_{V1RM}$ method require specific methodologies, such as a pause between the eccentric and concentric phases of movement, and exercise movements (bench press), or equipment (Smith machine) that involves minimal horizontal barbell movement. However, large mass compound free-weight exercises are often preferred over Smith machine exercises due to its higher functionality for sports (Fleck & Kraemer, 2014, pp. 52-54). Therefore, due to the questionable accuracy of this 1RM prediction method for large mass compound free-weight exercises, it appears this method should not be used to accurately monitor day-to-day fluctuations in maximal strength for the squat exercise.

Athlete Fatigue Monitoring

Fatigue in athletic populations has been described as a complex multi-faceted phenomenon, characterised by a reduced ability to generate muscle force (Phillips, 2015, pp. 3-4). The impact of fatigue on athletes requires coaches to modify training sessions to avoid non-functional overreaching, injury, and to ensure athletes can perform at their maximum during competition (Hausswirth & Mujika, 2013). It is common for coaches to monitor fatigue during resistance training by assessing decreases in force or velocity using the isometric mid-thigh pull, or the CMJ, respectively (Cormie, McGuigan, & Newton, 2010; Haff, Ruben, Lider, Twine, & Cormie, 2015).

CMJ assessments can be implemented into training programs to assess movement velocity decreases from strength training, sport specific training or competitive matches (Cormack, Newton, McGuigan, & Doyle, 2008). CMJ assessments are highly reliable, practical, and impose minimal physiological strain on an athlete, which allows the repeatability of the assessment within a short period of time (McLellan, Lovell, & Gass, 2011; Taylor, Cronin, Gill, Chapman, & Sheppard, 2010). Furthermore, given the time efficient nature in which a CMJ assessment can be administered, data can be quickly analysed to determine if an athlete's output is lower than baseline levels. Despite the benefits of CMJ assessments (valid and reliable), these assessments do not precisely identify how training loads can be modified for a specific exercise. Therefore, fatigue monitoring methods that can be integrated within prescribed training sessions and can accurately be used to modify training loads for specific exercises would be of great interest to strength and conditioning practitioners.

Combining objective with subjective measures of fatigue provides strength coaches with an insight into how an individual is coping with training prescription. The Borg rating of perceived exertion scale (RPE) is a widely accepted subjective monitoring tool for quantifying exercise intensity (Borg, 1982). This scale measure provides instantaneous feedback regarding the level of strain or difficulty an athlete perceives they experienced from the session completed as assessed by a numbered scale (rest 1 – maximal 10). Understanding the perceived difficultly of a session can be beneficial when prescribing session intensity and volume. Furthermore, a session RPE scale eliminates the need for 1RM assessments to determine working loads and the intensity of the session can simply be prescribed to match a desired RPE rating (Foster et al., 2001). The use of an RPE scale is especially beneficial for coaches with limited time or equipment. It does need to be considered, that the use of RPE is highly subjective and the use of numerous objective fatigue monitoring tools should be implemented by a coach to effectively determine an athlete's readiness for training.

Conclusion

Measuring movement velocity has recently been implemented in resistance training to provide an advantage over conventional 1RM prescription as it considers daily fluctuations in athletes' performance output. Introduction of a LPT presents a non-invasive method to quantify athletic performance for resistance training. The measurement of movement velocity relies on the inverse linear relationship which exists between load and velocity for resistance training exercises. Therefore, given maximal effort is provided during the concentric phase of an exercise, it is anticipated heavier loads will not exude the same velocity as lighter loads lifted. Multiple variables are measured using LPTs however, it is suggested that mean concentric velocity is most appropriate when creating an individual's LVP. The purpose of an LVP is to provide individualised baseline movement velocity data so that sessional training loads may be modified due to gains in maximal strength (higher velocities produced against a submaximal load compared to the LVP) or reduced to avoid exacerbating fatigue.

Due to the strong inverse linear relationship between load and velocity, the changes in movement velocity and the return of maximal strength is expected to be similar. Modifying sessional loads to consider daily readiness may reduce fatigue and enhance recovery. Further research is required to determine the effect fatigue has on movement velocity following resistance training sessions to validate this as a method of monitoring athlete performance.

Methods

Study Participants

Fifteen (n=15) strength trained male participants were recruited for this study (24.1 ± 5.2 yrs, 78.9 ± 8.2 kg, resistance training experience 4.6 ± 3.3 yrs). Inclusion criteria consisted of participants being able to perform the back-squat exercise with at least 1.5 times their body weight, currently completing two strength-based resistance training sessions per week, have had a minimum of 6 months resistance training experience, and no current musculoskeletal injuries. Prior to testing, participants received information regarding the study, completed a medical questionnaire and provided informed written consent. Ethics approval was obtained from the University Human Research Ethics Committee.

Experimental Protocol

Participants attended the laboratory on 13 occasions during a 3-week period. They were instructed not to perform additional exercise during this period. The initial session familiarised the participants with the desired squatting technique and training protocols, the second session involved the completion of a baseline 1RM assessment to quantify maximal strength, so that relative loads could be prescribed throughout the study. The third session developed the individuals load-velocity profile (LVP) which established their individualised baseline velocities. This required participants to complete five sets of the back-squat exercise at loads of 20% (5 repetitions), 40% (3 repetitions), and 60% (3 repetitions) 1RM, followed by 80% and 90% 1RM for a single repetition. Banyard et al. (2017) established that movement velocity at relative intensities between 20-90% 1RM are reliable and recommend that these relative intensities should be included in the development of the LVP.

For the remainder of the sessions, participants completed a group of strength-orientated sessions (5 sets of 5 repetitions at 80% 1RM) and a group of power-orientated sessions (6 sets of 3 repetitions at 50% 1RM), where repetitions were instructed to be performed with maximal intent. These sessions were completed in a randomised order for the back-squat exercise only. Upon completion of each session, a series of 1RM assessments were measured at time points 24, 48, 72 and 96 hours to determine the rate at which an individual's strength and velocity returned to baseline (obtained in the second session). Both maximal strength (1RM) and movement velocity (mean velocity and peak velocity) were assessed during this time. A verbal sessional difficulty rating using Borg's 10-point RPE scale was measured immediately after the training and 1RM sessions, to monitor how difficult individuals perceived a session to be. Additionally, 3 repetitions for the barbell CMJ exercise were completed immediately after the warm up and immediately after the completion of the last set for every session to monitor within session variation of movement velocity.

Data Collection

Back-Squat Repetition Maximum Testing

Prior to completing the group of strength and power exercise sessions, participants completed a standardised warm-up procedure consisting of pedalling on a cycle ergometer for five minutes (Monark Ergomedic 828 E, Australia) at a moderate, self-selected intensity followed by five minutes of prescribed dynamic stretches. Each 1RM assessment required the participant to complete five warm-up sets comprising of 5 repetitions at 20%, 3 repetitions at 40% and 60%

followed by a single repetition at both 80% and 90%. Throughout each repetition, it was asked that the eccentric (downward) phase was controlled whilst the concentric (upward) phase was completed as fast as possible. The eccentric phase was completed when the knees reached a 90-degree angle, when the concentric phase could then commence. Verbal cues were provided expressing when the eccentric phase concluded, and participants could begin the up phase of the squat (Cronin & Hansen, 2005). Upon completion of the warm-up, the current load (90%) was increased by approximately 5% and a single repetition was completed (Miller, 2012). The weight was continually increased at this rate after each successful lift until the participant could no longer complete a full repetition. A repetition was deemed successful if the participant used correct technique to be able to reach a pre-determined squat depth and return to the starting position. The individuals 1RM was determined by the heaviest successful repetition and attempts ceased once no further weight could be lifted with the above instructions. Participants were allowed 2 minutes of passive recovery between warm-up sets and 3 minutes for 1RM attempts. A maximum of 5, 1RM attempts were granted to ensure the test was attempted to failure.

Determining the Load-Velocity Relationship

Following the 1RM testing completed in the second session, an individualised LVP was established for each participant. This was created by calculating the fastest average concentric velocity for each of the loads lifted at 20% (5-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition) and 90% (1-repetition) 1RM. Relative loads were then used for the training protocols (which were established from the baseline 1RM session) as opposed to estimated loads to provide training specificity. A cable linear position transducer (LPT) (GymAware Powertool; Kinetic Performance Technology, Canberra, Australia) was used to measure the mean concentric velocity (MV) and peak velocity (PV) of each repetition. The sampling frequency used was 50 samples per second. The LPT was magnetically fixed to the floor directly below the barbells position during the squatting movement, and the device's retractable cord was positioned on the inside of the barbell collar. All successful lifts were those in which minimal unstable bar movement was observed. However, these experienced lifters were able to stabilise the bar throughout the lifts. Data was transmitted via Bluetooth to an I-Pad (Apple, USA) utilising the Gymaware software (V.2.5)

Data Analysis

For sets that included more than one repetition, the repetition with the fastest MV was used for the LVP. From this data, a scatter plot figure was constructed in Microsoft Excel (2016) with the relative load placed on the x-axis and the velocity on the y-axis. A line of best fit was then applied, and a linear regression equation was calculated. This provided each participant with a baseline individualised LVP. The same analysis was completed for the PV. Baseline maximal strength (1RM) collected during the baseline 1RM session, was compared to maximal strength at time points 24, 48, 72 and 96 hours following the training sessions. Data collected for PV of CMJ completed prior to each testing session were also compared against baseline PV for the CMJ.

Statistical Analysis

Statistical analyses were undertaken using Statistical Package for Social Sciences (SPSS) software, version 22 (IBM corporation, USA). Paired sample t-tests were completed for each relative load at baseline and each time point for all participants. This was performed for all MV, PV, CMJ and maximal strength data. Effect sizes were then reported using Cohen's D with values representing small (0.2-0.49), medium (0.5-0.79) and large (0.8 or above) effects (Cohen, 1992). Both mean and peak velocity were used for all lifts. All data was screened for normality. Any data points that were deemed as erroneous due to maximal intent not performed for a given lift, were removed from analysis.

Results

Descriptive Results

The mean age for the participants was 24.1 ± 5.2 years with a body weight of 78.9 ± 8.2kg. The measured mean baseline 1RM load of the participants was 132.5 ± 28.3kg. This resulted in the mean relative 1RM load (1RM load/body weight) to be 1.7 ± 0.2. Tables 1 and 2 show the return of MV, PV and peak force following the strength-orientated and power-orientated training sessions respectively for each of the time points (baseline, 24h, 48h, 72h and 96hr). The changes in max strength from baseline to 96h for both the strength-orientated and power-orientated session are reported in Figure 3. The differences of PV for CMJ from each session is also reported in Figure 4.

Strength-Orientated Training Velocities and Force

Table 1 reports the changes in MV, PV and peak force for time points 24h, 48h, 72h and 96h compared to baseline scores after completing the strength-orientated training protocol. The ES are also reported comparing MV and PV scores for each time point to baseline. Additionally, figure 1 represents the MV and PV LVP at baseline, 24h and 48h following the strength-orientated training protocol. For 24h, MV was shown to have a large ES for loads of 60, 80 and 90%1RM. A medium ES was observed for 40%1RM. ES for PV at 24h was shown to be large at 90%1RM and medium for 60 and 80%1RM. For MV at 48h, a medium ES was found at 60, 80 and 90%1RM. Similarly, the ES for PV at loads of 60% and 80% were medium. Trivial to small ES were observed for all other relative loads and time points. For MV at 1RM loads, a medium ES was shown at 24h, with small ES for 48 and 96h. No changes were reported at 72h.

PV showed to have small ES at 24, 72 and 96h with no change reported at 48h. Only small to trivial ES were reported for peak force of all relative loads and time points.

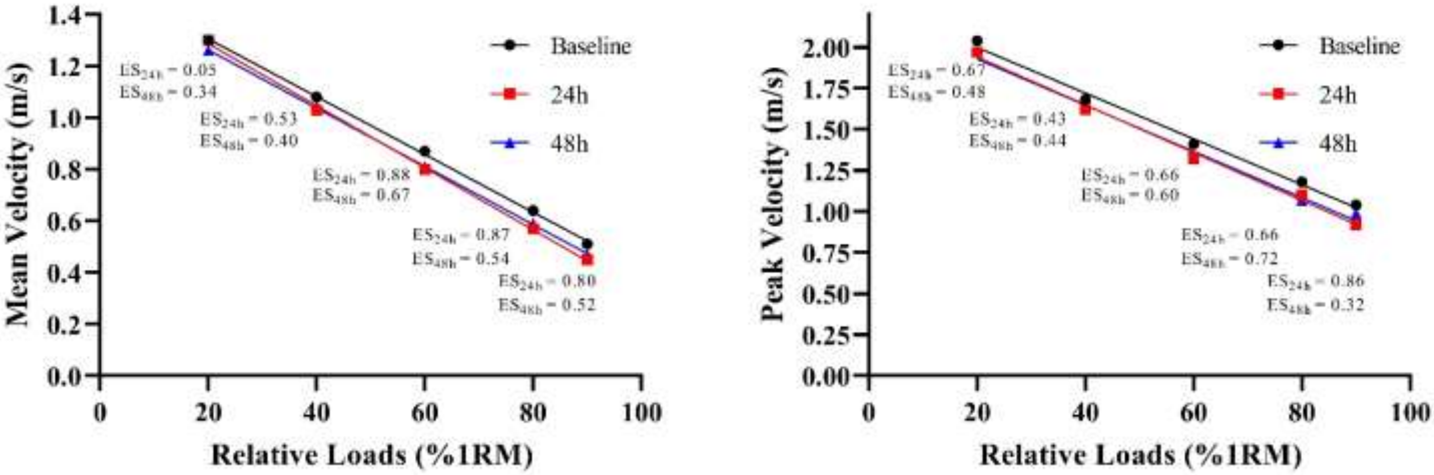

Figure 1. The load-velocity profiles of mean velocity (MV) and peak velocity (PV) compared at baseline, 24 and 48h following the strength-orientated training session.

Table 1. Mean velocity (MV), peak velocity (PV) and peak force following the strength-orientated training session at time points baseline, 24h, 48h, 72h and 96h for relative loads of 20, 40, 60, 80, 90%1RM and 1RM.

	%1RM	MV (m/s)	PV (m/s)	Peak Force (N)
Baseline	20	1.30 ± 0.09	2.04 ± 0.01	2313.53 ± 531.65
	40	1.08 ± 0.09	1.68 ± 0.12	2490.16 ± 569.15
	60	0.87 ± 0.08	1.41 ± 0.10	2628.71 ± 642.47
	80	0.64 ± 0.06	1.18 ± 0.10	2572.28 ± 526.12
	90	0.51 ± 0.06	1.04 ± 0.12	2679.17 ± 537.27
	1RM	0.31 ± 0.05	0.85 ± 0.14	2699.03 ± 548.08
24 hours	20	1.30 ± 0.17	1.97 ± 0.10[b]	2263.59 ± 482.29
	40	1.03 ± 0.11[b]	1.62 ± 0.17[c]	2347.16 ± 486.96[c]
	60	0.80 ± 0.10[a]	1.33 ± 0.15[b]	2476.26 ± 558.18[c]
	80	0.57 ± 0.08[a]	1.10 ± 0.13[b]	2524.30 ± 513.85
	90	0.45 ± 0.09[a]	0.92 ± 0.15[a]	2579.59 ± 537.27
	1RM	0.28 ± 0.05[b]	0.80 ± 0.12[c]	2655.39 ± 508.75
48 hours	20	1.26 ± 0.14[c]	1.97 ± 0.19[c]	2272.67 ± 456.02
	40	1.04 ± 0.13[c]	1.62 ± 0.19[c]	2358.20 ± 465.27[c]
	60	0.81 ± 0.11[b]	1.32 ± 0.21[b]	2467.02 ± 607.34[c]
	80	0.59 ± 0.10[b]	1.07 ± 0.20[b]	2575.64 ± 564.66
	90	0.47 ± 0.07[b]	0.99 ± 0.16[c]	2643.63 ± 511.97
	1RM	0.29 ± 0.06[c]	0.82 ± 0.17	2678.61 ± 512.99
72 hours	20	1.29 ± 0.12	2.04 ± 0.14	2298.37 ± 507.99
	40	1.06 ± 0.11[c]	1.64 ± 0.16[c]	2376.30 ± 464.24[c]
	60	0.84 ± 0.09[c]	1.39 ± 0.15	2518.57 ± 566.30
	80	0.60 ± 0.07[c]	1.09 ± 0.14[b]	2515.75 ± 461.30
	90	0.48 ± 0.07[c]	0.99 ± 0.13[c]	2621.18 ± 531.22
	1RM	0.30 ± 0.04	0.80 ± 0.12[c]	2662.44 ± 530.80
96 hours	20	1.30 ± 0.10	2.01 ± 0.13[c]	2339.67 ± 478.50
	40	1.06 ± 0.10	1.66 ± 0.14	2400.06 ± 434.04
	60	0.85 ± 0.09[c]	1.37 ± 0.12[c]	2546.64 ± 550.92
	80	0.63 ± 0.08	1.12 ± 0.14[c]	2575.03 ± 527.03
	90	0.49 ± 0.08[c]	0.98 ± 0.20[c]	2612.12 ± 535.64
	1RM	0.29 ± 0.06[c]	0.79 ± 0.17[c]	2714.67 ± 611.89

[a] – large, [b] – medium, [c] – small effect size difference from baseline.

Power-Orientated Training Velocities and Force

Table 2 reports the changes in MV, PV and peak force at time points 24h, 48h, 72h and 96h compared to baseline scores following the power-orientated training session. Similarly, figure 2 represents the MV and PV LVP at baseline, 24h and 48h following the power-orientated training session. For all time points only small or trivial ES were found for all relative loads. At 1RM loads, medium ES were observed at 24 and 72h. Small ES were found at 48 and 96h. PV for 1RM loads showed a large ES at 96h, medium ES at 48 and 72h, whilst small ES were shown at 24h. No differences in effect size were found at any relative loads or time point for peak force.

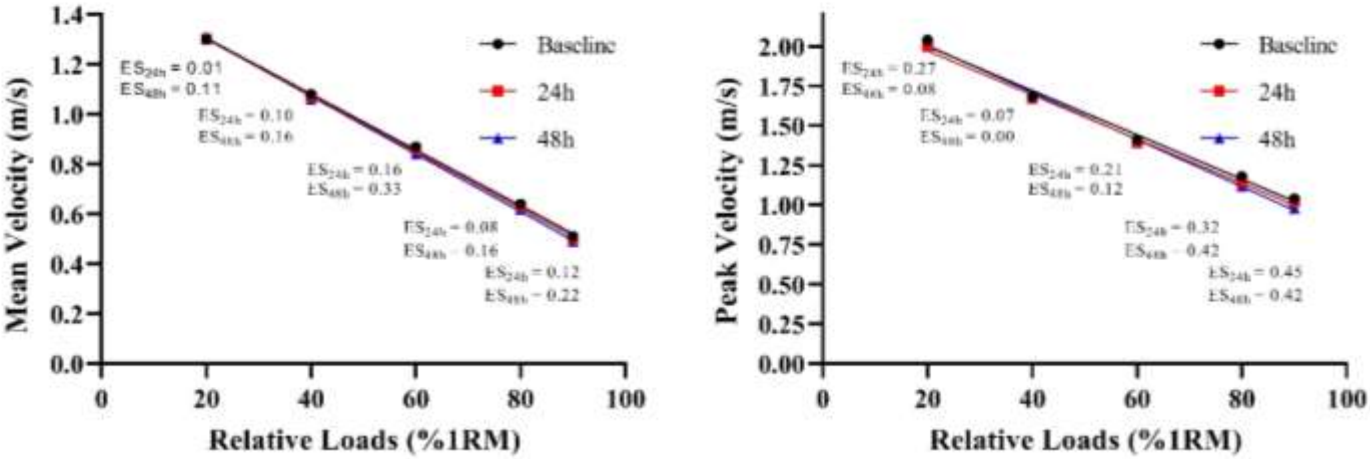

Figure 2. The load-velocity profiles of mean velocity (MV) and peak velocity (PV) compared at baseline, 24 and 48h following the power-orientated training session.

Table 2. Mean velocity (MV), peak velocity (PV) and peak force following the power-orientated training session at time points 24h, 48h, 72h and 96h for relative loads of 20, 40, 60, 80, 90%1RM and 1RM.

	%1RM	MV (m/s)	PV (m/s)	Peak Force (N)
Baseline	20	1.30 ± 0.09	2.04 ± 0.10	2313.53 ± 531.65
	40	1.08 ± 0.09	1.68 ± 0.12	2490.16 ± 569.15
	60	0.87 ± 0.08	1.41 ± 0.10	2628.71 ± 642.47
	80	0.64 ± 0.06	1.18 ± 0.10	2572.28 ± 526.12
	90	0.51 ± 0.06	1.04 ± 0.12	2679.17 ± 537.27
	1RM	0.31 ± 0.05	0.85 ± 0.14	2699.03 ± 548.08
24 hours	20	1.30 ± 0.14	2.00 ± 0.18[c]	2370.87 ± 501.78
	40	1.07 ± 0.11	1.67 ± 0.15	2492.44 ± 523.75
	60	0.86 ± 0.10	1.39 ± 0.12[c]	2594.26 ± 553.51
	80	0.63 ± 0.10	1.14 ± 0.15[c]	2617.42 ± 554.55
	90	0.50 ± 0.08	1.02 ± 0.14	2694.11 ± 550.71
	1RM	0.27 ± 0.05[b]	0.78 ± 0.16[c]	2688.02 ± 561.08
48 hours	20	1.31 ± 0.14	2.03 ± 0.23	2378.36 ± 454.29
	40	1.06 ± 0.13	1.68 ± 0.17	2458.04 ± 510.73
	60	0.84 ± 0.09[c]	1.40 ± 0.15	2597.13 ± 504.72
	80	0.62 ± 0.09	1.12 ± 0.14[c]	2583.25 ± 516.37
	90	0.49 ± 0.08[c]	0.98 ± 0.16[c]	2652.89 ± 540.63
	1RM	0.29 ± 0.06[c]	0.74 ± 0.18[b]	2674.11 ± 581.37
72 hours	20	1.29 ± 0.16	2.02 ± 0.21	2340.91 ± 456.15
	40	1.06 ± 0.13[c]	1.67 ± 0.16	2410.63 ± 481.77
	60	0.83 ± 0.11[c]	1.39 ± 0.16	2532.72 ± 485.01
	80	0.63 ± 0.10	1.15 ± 0.13	2567.47 ± 497.06
	90	0.47 ± 0.08[c]	0.96 ± 0.12[c]	2654.43 ± 477.96
	1RM	0.27 ± 0.06[b]	0.77 ± 0.16[b]	2644.57 ± 505.55
96 hours	20	1.33 ± 0.14[c]	2.04 ± 0.17	2385.90 ± 418.01
	40	1.08 ± 0.13	1.70 ± 0.17	2412.58 ± 466.41
	60	0.87 ± 0.15	1.42 ± 0.18	2559.09 ± 552.84
	80	0.6 ± 0.09[c]	1.12 ± 0.15	2528.76 ± 439.73
	90	0.49 ± 0.08[c]	0.97 ± 0.16[c]	2616.64 ± 518.10
	1RM	0.28 ± 0.06[c]	0.74 ± 0.12[a]	2674.06 ± 575.12

[a] – large, [b] – medium, [c] – small effect size difference from baseline.

Maximal Strength Return

Figure 3 reports the 1RM scores at each time point after both the strength and power-orientated training sessions. For the strength-orientated session, no significant differences in 1RM loads were observed at any of the time points compared to baseline. The results were the same for all time points following the power-orientated session, where no significant differences were observed.

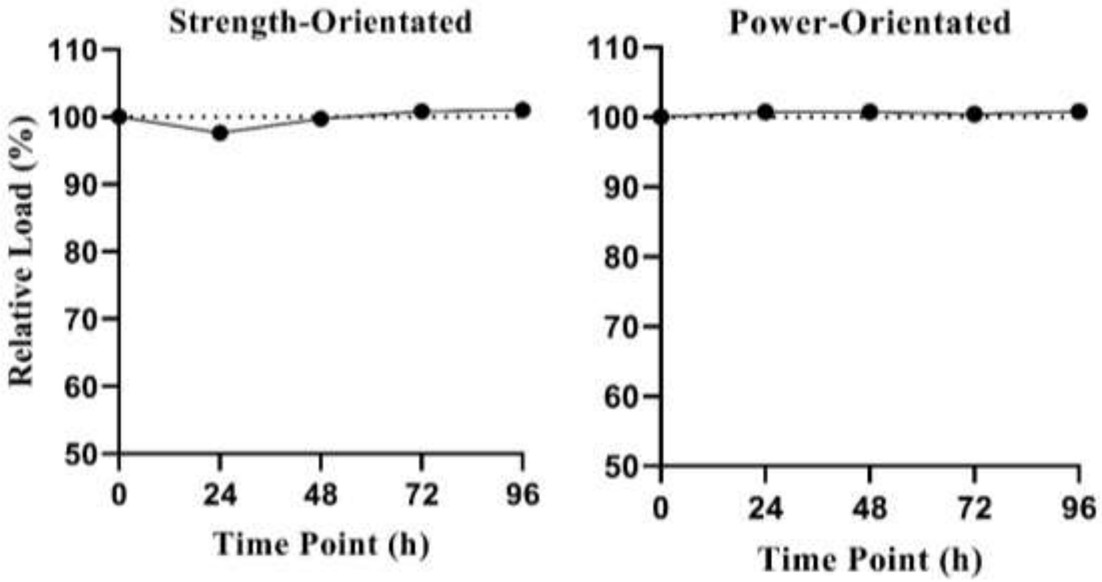

Figure 3. The return of relative max strength (kg) measured by 1RM scores from baseline to time points 24h, 48h, 72h and 96h following the strength-orientated or power-orientated training session.

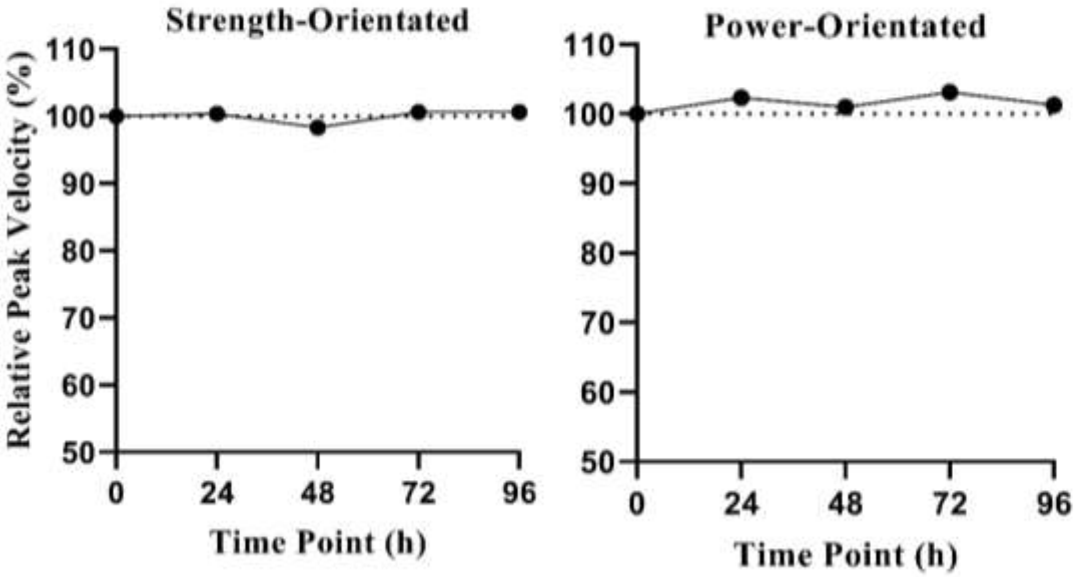

Figure 4. Relative peak velocity (m/s) of countermovement jumps from baseline to time points 24h, 48h, 72h and 96h following the strength-orientated or power-orientated training session.

Pre-Testing Countermovement Jump Peak Velocities

Figure 4 reports the PV recorded for the countermovement jump before the commencement of the 1RM sessions at baseline and timepoints 24h, 48h, 72h and 96h. For the strength-orientated session, no significant differences were shown at any of the time points compared to baseline. Similarly, no significant differences were observed for any time point for the power-orientated training protocol.

Discussion

The main aims of this study were to quantify the time course changes in velocity (20, 40, 60, 80, 90%1RM and 1RM) and maximal strength at 24, 48, 72, and 96h after a typical strength-orientated and power-orientated resistance training load for the back-squat exercise. Large to moderate declines in MV and PV were observed for loads 40, 60, 80, 90%1RM, and 1RM at 24 and 48h following the strength-orientated training session. However, only small to trivial changes in MV and PV were observed at any relative load or time points following the power-orientated training session. Interestingly, there was no meaningful change (small to trivial) in maximal strength at any time point following both the strength or power-orientated training sessions. In addition, further analysis showed there were no changes in peak force for the squat across the relative load spectrum, and no changes in PV for the CMJ at any time points following either experimental training sessions. These findings suggest the assessment of meaningful changes in squat velocity (MV and PV) are more sensitive, and possibly more appropriate indicators of readiness to train than maximal strength (1RM) or CMJ (PV) when training the back-squat exercise with strength-trained individuals. Therefore, coaches should monitor velocity to dictate appropriate sessional training loads, whilst not completely removing individuals from a scheduled resistance training session.

Following the strength-orientated training session, there were large to moderate declines in the squat velocity at relative loads of 40% and higher at 24h. At the 48h time point, velocities at these loads were still below baseline values but were not as decreased as loads at 24h. However, at 72 and 96h following the strength-orientated training session, there were no meaningful declines in velocity (MV and PV) at any relative load. This suggests that participants were not fully recovered until 72h following a heavy strength session even though there were no differences in maximal strength (1RM) or CMJ (PV). As a result, this may indicate that maximal strength and the CMJ assessment are not valid indicators of neuromuscular fatigue following fatiguing squat sessions. Previous research has established that a decline in velocity for repetitions of a designated load, strongly correlates with markers of neuromuscular fatigue (Sanchez-Medina & González-Badillo (2011). Although we did not directly measure type II fibre fatigue, it is suggested the type II fibres were not fully recovered to generate baseline velocity measures for loads greater than and equal to 60%1RM. Research by Cheng and Rice (2005) evaluated the recovery of velocity up to 10-minutes following maximal voluntary contractions for the leg extension exercise on a Biodex dynamometer. This study required participants to complete leg extensions with maximal intent until velocity declined to below 65% of baseline levels. It was reported that velocity was not recovered to baseline levels until 3-minutes after the exercise protocol. It is known that training with velocities as close to the maximal attainable velocity as possible will increase the neuromuscular stimuli to maximise strength adaptations compared to training with less than optimal velocities. Therefore, our findings suggest that training for maximal strength within 48h of completing a strength-orientated training session (≥60%1RM) could reduce desired training adaptations and delay recovery, since the individual would be training with lower velocities than their maximal attainable velocity. However, since there were no meaningful changes in MV and PV (≤40%1RM) in the days following the strength session, a coach could potentially prescribe a power training session with there being no ill effects.

In the days following the power-orientated training session, there was no meaningful changes in movement velocity at any relative load. This meant that individuals could produce their maximal attainable movement velocity at all relative loads for each time point. Considering typical power training utilises maximal repeatable repetitions whilst targeting maximal power adaptations, it is important that the training stimulus is relatively non-fatiguing (Legaz-Arrese, Reverter-Masia, Munguía-Izquerdo, & Ceballos-Gurrola, 2007). The results of the current study are in accordance with previous research showing that individuals have very little decline in movement velocity within a power-orientated training session, as shown in the CMJ exercise (Pérez-Castilla, García-Ramos, Padial, Morales-Artacho, & Feriche, 2018a). Pérez-Castilla et al. (2018) determined that power-orientated training sessions induce minimal fatigue when performing the Smith machine CMJ. It was observed that when training with a movement velocity loss threshold of 10%, individuals could perform repetitions at faster velocities with a small degree of fatigue. This was by design as the repetitions performed in power training should be performed with the highest attainable movement velocity output. This finding has implications for prescription of resistance training sessions by coaches. It would be appropriate to deliver power-orientated training sessions when it is desired that athletes are not overly stimulated and performing resistance training will not affect subsequent performance levels.

Despite the differing loads for the training protocols in this study, maximal strength was shown not to fluctuate at any time point. 1RM assessments have previously been used to determine baseline maximal strength levels, and subsequent testing can detect improvements from training stimuli (Haff & Triplett, 2016; Inness et al., 2016). Furthermore, it has been suggested the use of predicted 1RMs can identify if an individual is recovered from a previous training session (Raeder et al., 2016). A study by Hughes, Banyard, Dempsey, Peiffer and Scott (In Review) reported that if you perform strength training to failure, maximal strength will decrease in the subsequent days. Participants were asked to perform three sets at 70%1RM for the back-squat exercise to volitional failure. At 24 and 48h after the training protocol, measured 1RM was significantly lower than resting levels ($p < .01$). The findings of this study contrast with the results from the present study. A reason for this may be that Hughes et al., (In Review) performed training to failure. Literature suggests training to failure is not necessary to elicit increased adaptations of strength and power (Izquierdo et al., 2006). Based on this finding, training according to typical strength and power training recommendations, does not result in decreases in maximal strength following the session. Therefore, VBT may better indicate if an individual has recovered from a resistance training session than traditional 1RM assessments.

The measurement of peak force was also shown not to decrease following the training protocols. It has been found that as load increases so does peak force (Stone et al., 2003). Therefore, given maximal strength did not deviate, it was expected that force would not either. Peak force is often measured using various lower upper body exercises to determine maximal force generating capacity (Kobayashi et al., 2013; Wang et al., 2016). Considering the relationship between force and load it is important to note that force did not decline following the training protocols of the present study. This suggests that considering maximal strength and peak force does not acutely correlate with changes in movement velocity, these measurements may not accurately reflect an individual's readiness to train following fatiguing sessions.

Previous studies have utilised the CMJ assessment to measure fatigue and recovery through changes in PV, peak power and jump height (Cormie, McBride, & McCaulley, 2009; Kennedy & Drake, 2017). The CMJ was chosen as our criterion measure to determine whether a participant had recovered from the experimental training sessions in accordance with previous research. However, even though previous studies have utilised the CMJ assessment to monitor recovery and return to play, the findings of the present study suggest the CMJ may not be sensitive enough to monitor athletes following resistance training sessions. However, in the present study we found no change in PV at any time point in the days following both the strength and power-orientated training session. This may have been because even though the same musculature was stressed in the training sessions (i.e. lower body triple flexion/extension movement), particularly during the strength-orientated training session, the CMJ is an explosive movement performed with low intensity, limited self-selected range, with sub maximal loads and was not affected by the prescribed training protocols. Therefore, using the

CMJ may not be a valid exercise to assess the capabilities of an individual to perform a back squat with maximal attainable velocity.

Conclusion

This study reported the time course changes of movement velocity following typical resistance training sessions. The partial acceptance of the null and alternate hypothesis for the first research question were made. Additionally, the null hypothesis was fully accepted for the second research question and several practical applications for monitoring of individuals during resistance training may be used to better identify daily readiness. The differing results in velocity changes from strength and power-orientated resistance training may be used by coaches to determine when athletes should be performing desired sessions. As previously discussed, if maximal attainable movement velocity cannot be achieved until 72h following strength-orientated training, it may be beneficial for a coach to avoid prescribing this form of training before this time. This will allow individuals to perform their next session in a non-fatigued state so that desired training adaptations can be effectively targeted. Alternatively, following a typical power-orientated session, baseline movement velocity could be replicated within 24h of completing the session. Therefore, power training could be performed in subsequent days or in conjunction with strength-orientated training as movement velocity was not affected at the lower relative loads for this type of training. Furthermore, measuring velocity may present an alternative to other strength measures such as maximal strength, peak force and CMJ which were all proven to not diminish following resistance training.

Applications of this study may suggest movement velocity better reflects the training output of an individual for a given day. In which case coaches could measure submaximal loads within a warm-up to determine if an individual can attain maximal movement velocity for that session. If velocities are lower than baseline levels, training can be adjusted to avoid over-training and prolonged fatigue.

Future Research

From the results of this study, future research should consider:

1. Further examination of different exercises and the time course changes of velocity and maximal strength following training protocols.
2. Further examination of the effect of different resistance training protocols on time course changes of velocity and maximal strength.
3. Further examination of the effect of conditioning-based training on time course changes of velocity and maximal strength.
4. Further examination of the effect of a resistance training protocol that includes multiple exercises on the time course changes of velocity and maximal strength.

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