Autoregulation in resistance training: A comparison of subjective versus objective methods

Running Head: Velocity versus perception of effort training prescription

Kevin Shattock, MSc (Sports Coaching)[1], Jason C. Tee, PhD (Sport Science)[1,2]

[1]: Carnegie Applied Rugby Research (CARR) centre, Institute for Sport, Physical Activity and Leisure, Carnegie School of Sport, Leeds Beckett University, Leeds, United Kingdom

[2]: Department of Sport Studies, Faculty of Applied Sciences, Durban University of Technology, South Africa.

Address for correspondence:

Jason C. Tee,

Department of Sport Studies,

Faculty of Applied Sciences,

Durban University of Technology.

South Africa

Tel: +27 (0)13 373 6878

Email: jasonctee@gmail.com

Autoregulation in resistance training: A comparison of subjective versus objective methods

ABSRACT

Autoregulation (AR) is a resistance training periodization approach that adjusts training prescription in response to individual rates of athlete adaptation. AR training prescription can make use of either subjective (rating of perceived exertion - RPE) or objective (barbell velocity) intensity descriptors. The aim of this research was to compare the efficacy of these two approaches in improving sport specific physical performance measures. Using a randomized crossover design, 20 amateur rugby union players completed two six-week blocks of training with training intensity prescribed using either objective velocity based (VB) (measured using a wearable accelerometer device) or objective RPE based intensity prescriptions. Training volume was matched for both groups while training intensity was equivalent but prescribed using either VB or RPE measures. Performance measurements were countermovement jump (CMJ), 1RM back squat and bench press, and 10, 20 and 40 meters sprint. Testing was conducted prior to, and immediately following each training block. The likelihood that observed changes in performance measures were meaningful was assessed using magnitude--based decisions. Both training programs induced practically meaningful improvements in CMJ (VB *most likely* +8.2, ±1.1%; RPE *likely* +3.8, ± 0.9%), back squat (VB *most likely* +7.5, ±1.5%; RPE *possibly* +3.5, ± 1.8%) and bench press (VB *most likely* +7.7, ±2.1%; RPE *possibly* +3.8, ± 0.9%). Changes in sprint test performance were *very likely trivial* for both programs. Objective AR programming resulted in larger improvements in CMJ (*likely* 4.2, ±1.2%), squat (*likely* 3.7, ±1.5%) performance, and bench press (*possibly* 3.7, ± 1.5%) performance. AR periodization improved strength and CMJ, but not sprint performance. AR effects are augmented through the use of objective intensity prescription.

Keywords: velocity-based, RPE, periodization, training response, reps in reserve

INTRODUCTION

Resistance training results in improvements in strength, power and speed and reduces the risk of injury in a wide range of athletic populations (40). In order to achieve these adaptations, strength and conditioning (S&C) coaches prescribe training by manipulating the type, volume, frequency and intensity of training (5,24). Exercise intensity is generally acknowledged as the most important stimulus for strength gain (13). Traditionally, the intensity of resistance training has been described through the use of relative load, following the determination of athletes one repetition maximum load (1RM) (13,15). Once 1RM values are known for each exercise, the S&C coach will prescribe a relative load, (% of 1RM) dependent of the physiological adaptation sought, alongside the number of sets and reps to be performed (42).

While this approach to prescribing strength training intensity has been well described, it is not without limitations. The determination of 1RM is time consuming, consisting of a trial and error approach, in which the athlete progressively lifts greater loads until the last successful lift is determined (32). This approach is often impractical for large groups and may be associated with risk of injury if technique is not robust, or athletes are inexperienced (22). As a result, S&C coaches often only test the main lifts (e.g. back squat, bench press, prone row), and choose to estimate or derive auxiliary or assistance exercise (e.g. upright row, lunge) loads, which may lead to inaccurate training prescriptions (45). Furthermore, participants may improve their 1RM with time periods as short as 1-2 weeks following the commencement of resistance training (1,19). As such, the 1RM established at the start of a training cycle, may not correspond to the actual 1RM at the end of week 1, 2, 3 or 4 of a training cycle, leading to further inaccuracies in intensity prescription. In addition, athletes experience daily variations in neuromuscular performance (21,33) as a result of factors such as fatigue (11), nutrition (25), sleep (35) and stress (28). As a result, actual 1RM values vary across a micro cycle, meaning the loads prescribed for each particular training session may not necessarily represent the desired training intensity (22,33). These limitations suggest that seeking alternative intensity prescription protocols that are more sensitive to daily fluctuations in performance in strength training, would be beneficial to athletes (24).

An alternative approach is represented by the concept of autoregulation, a resistance training periodization approach that adjusts training prescription in response to individual rates of athlete adaptation (27). The premise of autoregulation methodology is that daily training prescription is adjusted to the athlete's 'on the day' capabilities using measures that are sensitive to the athlete's acute performance potential. A number of autoregulatory approaches to resistance training have previously described including autoregulatory progressive resistance exercise (APRE) (27), perceived exertion methods (utilizing the rating of perceived exertion (RPE) scale or the repetitions in reserve (RIR) method) (17,18) and velocity-based training (VBT) (9).

The VBT approach is an objective method that utilizes measurement of bar velocity to estimate the intensity of a lift. This estimation is based on the well-established linear relationship between the absolute load of the lift and the velocity that can be achieved, with concentric movement velocity progressively decreasing as individuals progress towards their 1RM (7,15,37). This relationship has been shown to be sensitive to changes in neuromuscular fatigue (36), and thus VBT has been proposed by a number of researchers as a method of training prescription that is sensitive to daily variations in fatigue (22,26,31). Recent research has demonstrated that VBT training result in lower levels of mechanical stress during training (4), and similar levels of physical adaptation to traditional percentage-based programs, but with less absolute load (9). While these initial results are promising, the efficacy of VBT has yet to be established in a broad range of contexts. In addition, despite the increasing accessibility of VBT devices (22), the cost of this technology remains prohibitive for many training environments.

A plausible alternative to the use of VBT for autoregulatory training prescription is the subjective estimation of perceived exertion. Two methods of quantifying perceived exertion (RPE (41) and RIR (46)) have been developed and these can be used independently or in parallel. Similarly, to bar velocity, subject ratings of perceived exertion are linearly related to relative load, with perceived exertion increasing as participant lift progressively higher percentages of their 1RM (46). Perceived exertion measures are also sensitive to changes in athlete strength levels (14), and thus can be used to adjust training for daily fluctuations in an athletes' strength levels. The only study to date to compare the training outcomes of traditional and perceived exertion training prescriptions demonstrated similar adaptations from the two methods (18).

The arguments presented above provide a strong rationale for the use of autoregulation for resistance training prescription, but practitioners may have questions regarding which approach is most effective. To the authors knowledge, no previous research has made a direct comparison between objective and subjective autoregulation methods. Understanding the utility of these methods may lead to improved practices within strength and conditioning training. Therefore, it is the aim of this research to determine the effectiveness of these two prescription methodologies in improving physical performance.

METHODS

Experimental Approach to the Problem

A randomized cross-over research design was utilized to determine the effect of subjective (RPE/RIR) and objective (VBT) autoregulation prescription methods on sport specific performance tests. Athletes from a semi-professional senior men's rugby union club were randomly assigned to two different group before undertaking 12 weeks of general preparation preseason training to prepare for the upcoming rugby season. The aim of the training program was to improve speed, strength and power as these physiological qualities are important determinants of performance within the sport (29). Within this training period, the two training groups completed two six-week training blocks with training intensity alternatively prescribed using either subjective or objective methods (Figure 1). The effectiveness of these methods was assessed by determining changes in strength, power and speed following each training block.

* * * Figure 1 near here * * *

Subjects

Twenty semi-professional rugby players from a single club participating in the United Kingdom's National League 3 North were recruited for this study. The criteria for inclusion within this study was as follows: (a) over the age of 18 years (b) training status of over two years (c) availability to participate in all training sessions and testing batteries. Subjects were informed of the purpose, rationale, risks and benefits of participation before signing institutionally approved consent documentation. Participation was voluntary, and no data was collected prior to approval. The study was approved by the Local Research Ethics Committee at Leeds Beckett University. The physical characteristics of the participants prior to participation in the training program are presented in table 1.

*** Table 1 near here ***

Procedures

Familiarization

All participants were familiar with the testing protocol as this battery is completed on a regular basis as part of the athlete monitoring protocol within the squad. The team's S&C coach generally prescribes training using the RPE/RIR approach; thus, all participants were familiar with this method. Participants completed one week of the velocity-based training protocol 4 weeks prior to the commencement on this study to ensure familiarization.

Performance testing

Performance testing sessions were conducted prior to the commencement of the study and following each training block. Participants rested for 48 hours prior to each performance testing session. Testing sessions took place over two days with a counter movement jump (CMJ) test, 1RM tests for back squat and bench press test taking place on day 1, and 10 m, 20 m and 40 m taking place 24 hours later on day 2. All testing sessions were conducted by a United Kingdom Strength and Conditioning Association (UKSCA) certified S&C coach who ensured adherence to the testing protocols. The specific protocols for each test are described below –

Counter Movement Jump

CMJ was assessed using the MyJump 2 (Version 1.0.11) smart device application, which measures jump height using flight time determined using the high-speed camera contained within the device (iPad 4, iOS 10.3.3, camera resolution 1080p/30fps). The MyJump application has been shown to be appropriately valid (ICC = 0.997) and reliable (CV = 3.4%) for the determination of jump height (2). Participants completed a standardized 5-minute warm up composed of lower body dynamic stretches and vertical jumps prior to testing. CMJ tests were conducted as per the manufacturer instructions (2), participants were instructed to keep their hands on the hips throughout the jump, perform a downward countermovement to a self-selected height, before jumping with maximum effort. Participants were instructed to keep their knees straight during the flight phase of the jump and to land in an upright position. Subjects were given three opportunities to complete the test, with the best performance recorded. Attempts were separated by 60 seconds of passive rest.

1RM back squat and bench press

1RM strength back squat and bench press were determined according to the National Strength and Conditioning Association's 1RM Testing Protocol (16). Participants completed submaximal repetitions of each exercise at approximately 50–80% 1RM to serve as both warm-up and determination of 1RM load. With each exercise, subjects were then given 6 attempts, with progressively increasing load to achieve 1RM. 3 – 5 minutes rest was used in between each attempt. Both test protocols were completed using a 2.13m (7ft) Olympic bar and free weights. Participants were required to back squat until the top of the thigh was parallel with the ground, which was visually determined by the lead researcher. Players then had to return to a standing position with adequate technique to record a 1-RM score. For the bench press, athletes lowered the barbell to touch the chest and then pushed the barbell until elbows were locked out while keeping the head, upper back and buttocks on the bench and feet firmly planted on the floor. The largest successful weight achieved in each exercise was recorded.

Sprint Testing

Speed was assessed using a single beam photocell timing system (Brower timing systems, IR Emit, USA) on a standard track surface with gates positioned at 10, 20 & 40 meters. Single beam timing systems have a similar error rate to dual beam timing systems following signal processing (10). Following a standardized warm-up consisting of light jogging, dynamic stretches, and submaximal sprint efforts, participants performed 2 maximal sprint efforts, from a start point of 0.5 m behind the first timing gate with 3 minutes passive rest between each attempt. Participants were instructed to begin in their own time and sprint as fast as possible through the final timing gate. The best split time over the two attempts were recorded for analysis. The reliability of this method has previously been determined as acceptable (CV for 10m, 20m and 40 = 3.1%, 1.8% and 1.3% respectively) (8).

Training prescription

Training prescriptions were based on the periodized progression through phases of maximal strength, strength-speed and speed-strength proposed by Suchomel et al. (2017) (39). A table aligning comparative training intensities across traditional percentage-based, perceived effort and VBT methods was constructed from previous research to be utilized for training intensity prescription (Table 2) (6,15,37,46). The training period was organized into two six-week training cycles, with the first training cycle focusing on the development of 'maximal strength' and the second cycle developing 'strength speed' (Table 3 & 4) (39). The maximal strength cycle consisted of four training sessions per week incorporating three exercises per session in an 8 x 3 set rep structure. Training intensity was prescribed using either subjective or objective methods that corresponded to loads >85% 1RM. During this training block participants completed session 1 and 2 on consecutive days, then rested for 1 day before completing session 3, followed by a further rest day before completing session 4. No rugby (technical or tactical) training was completed during this block. Similarly, the strength speed cycle consisted of three training sessions per week incorporating four exercises per session using a 6 x 4 set rep structure. Again, training intensity was prescribed using either subjective or objective methods, but for this training block intensities corresponded to 70-80% 1RM. During this training block, participants rested for 1 day following each training session. One rugby-based session took place following the three training sessions during this block, and consisted of handling drills, small sided games and drills focused on defensive principles. As such, the training volume for the two experimental conditions, subjective and objective was matched.

Auto-Regulation Methods

Subjective and objective prescription groups trained in the same facility, one after the other to ensure that each group was blinded to the intensities that the other groups was set and could not see what weights they were using. The objective training prescription group received wearable accelerometers (PUSH^{TM}, PUSH Inc., Toronto, Canada) and iPads (Apple, iPad 4, iOS 10.3.3) to provide immediate feedback on movement velocity. Accelerometer devices were worn on the top of the right forearm, 1-2 cm distal to the elbow crease, with the main button located proximally as per manufacturer's instruction for all training sessions. Data obtained from the accelerometer devices were recorded at a sampling rate of 200 Hz and transmitted to the PUSH^{TM} application (v3.1.2) on the iPad via a Bluetooth. PUSH^{TM} devices have been shown to have reasonable validity (r = 0.91-0.97) when compared to a gold standard 3D motion capture device (30) and have good reliability (CV = 5.0 %) (3). At the beginning of each training session, the exercises to be completed, the set and rep schemes and the required intensity described either subjectively or objectively (according to group allocation) were communicated to the participants. In the first week of the training program, participants self-selected loads for each exercise in line with the designated intensity prescription. Following the initial set of each exercise, participants would review either the mean concentric velocity achieved for each rep, or their level of perceived exertion for the entire set using RPE and RIR scales. If the velocity achieved for any two of the reps completed exceeded or did not achieve the specified velocity range, the weight was adjusted up or down to achieve the appropriate load. Similarly, if the subjective group participants perceived the set to be easier or harder than the prescribed intensity the weight was adjusted in the same way. For barbell exercises, weights were adjusted up or down in 5 kg increments at each step, while for dumbbell exercises the increments were 1kg per dumbbell. If the velocity or perception of exertion achieved was aligned with the prescribed intensity, no adjustments were made. This review and adjust cycle was repeated for each set until the prescribed number of sets were completed. The weights used by each participant for each set were recorded for the duration of the training intervention to allow for the calculation of total volume load. The load used in the final set of each training session was recorded and used as the initial resistance for the following week's training session. Following the completion of the six-week training block, the process was repeated with each group using the alternate method of training intensity prescription,

Statistical Analyses

Changes in performance measures from the beginning to the end of training blocks for each type of training prescription were assessed using the Wilcoxon signed rank test, due to non-normal distribution of the data, and are presented as % change, ± 90% confidence intervals. Between condition differences (objective vs. subjective) were assessed using the Wilcoxon signed rank test, by calculating Hedges' *g* effect sizes [90% Confidence limits], and by producing Gardner-Altman estimation plots to demonstrate the paired mean difference. Effect sizes were categorized as trivial (<0.2), small (0.20-0.59), medium (0.60-1.19), large (1.20-1.99) or very large (>2.0) (20). The likelihood that these effects were practically meaningful was assessed using magnitude-based decisions (20). The threshold for change considered to be practically important (the smallest worthwhile change; SWC) was set at 0.2 x between subject standard deviation (SD), based on Cohen's d effect size (ES) principle. The probability that the magnitude of change was greater than the SWC was rated as <0.5%, almost certainly not; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, almost certainly. Where the 90% Confidence Interval (CI) crossed both the upper and lower boundaries of the SWC (ES ± 0.2), the magnitude of change was described as unclear. For all analyses statistical significance accepted at the level of $p < 0.05$.

RESULTS

Compliance within the training program was 100% for both training blocks. Table 5 presents the changes in physical performance measures achieved under each training prescription condition. The individual and mean difference in response to each prescription condition is provided in figure 2. Both objective and subjective autoregulation programs resulted in statistically significant improvements in CMJ (objective $p = 0.0001$, subjective $p = 0.0003$), 1RM squat (objective $p = 0.0001$, subjective $p = 0.0002$) and 1RM bench press (objective $p = 0.0001$, subjective $p = 0.0002$) performance. For these performance tests, the objective prescription method displayed high likelihoods of practically meaningful improvement (all > 99.5% likelihood), while the improvements for the subjective prescription method were less certain (CMJ *likely* (75-95%), 1RM squat *possibly* (25-75%), 1RM bench press *likely* (75-95%)). There were significant and practically meaningful differences in response between prescription types which favored the objective autoregulation method for CMJ ($p = 0.00001$, *Almost certainly* large), 1RM squat ($p = 0.0001$, *Almost certainly* large) and 1RM bench press ($p = 0.003$, *Very likely* medium).

Changes in speed across all measured distances (10 m, 20 m, 40 m) were *almost certainly* trivial. Statistically significant changes were observed in 10 m time ($p = 0.028$) for the subjective method, and in 40 m time ($p = 0.001$) for the objective method, but these could not be interpreted as practically meaningful changes due to the small magnitude of the effect. There were statistically significant differences in effect between prescription type which favored the objective autoregulation method in each case (10 m $p = 0.214$, 20 m $p = 0.046$, 40 m $p = 0.043$), but these should not be over interpreted due to the lack of meaningful improvement in either group.

There was no statistical or practically meaningful difference in total volume lifted between training conditions (Subjective 153 395 ± 13 574 vs. Objective 149 270 ± 17 413 kg, $p = 0.457$, *unclear)*.

DISCUSSION

The main finding of this study is that the use of autoregulatory approaches to resistance training prescription induce positive adaptations in participant strength and power qualities. The extent of this improvement differed according the method used with objective autoregulation, making use of movement velocity for feedback, resulting in larger and more certain improvements in strength and power tests that subjective autoregulation.

The results align with previous findings. Recently, Dorrell et al., (2019) demonstrated improvements of in maximal squat (9%), maximal bench press (8%) and CMJ (5%) following a six-week velocity-based resistance training program (9). The magnitude of these improvements was similar to the ones demonstrated in this study (squat ↑ 7.5, ±1.5%; bench press ↑ 7.7, ±2.1%; CMJ ↑ 8.2, ±1.1%). Similarly, Helms et al., (2018) has demonstrated improvements in squat (9%) and bench press (15%) maximal strength following an eight-week subjective RPE based resistance training program (18). These improvements are significantly larger than the subjective group results obtained in this study (squat ↑ 3.5, ±0.8%, bench press↑

3.8, ±0.9%). These differences are likely the result of the longer training period (6 vs. 8 weeks) and differences in the overall program design. Collectively, these results demonstrate the utility of autoregulatory methods for improving physical performance through resistance training, presenting a viable alternative to traditional percentage-based prescription.

A novel aspect of this study was the comparison of two different approaches to autoregulation, rather than the more established approach of comparing autoregulatory methods with the traditional percentage-based approach (9,18,27). The information provided by this study will be useful for practitioners considering employing autoregulatory methods in their training plans. The results of this study indicate that if the resource is available to use velocity-based methods for training prescription, practitioners could expect improved adaptation versus objective autoregulation. On the other hand, both subjective and objective methods resulted in performance improvement indicating that access to VBT equipment does not need to be a barrier to implementing autoregulation in training.

This study was the first to assess the effect of autoregulatory training on acceleration and speed in the form of 10 to 40-meter runs. No discernible training effect was noted. This result contrasts directly with the observations of Randell et al., (2011) who found that objective performance feedback on bar velocity during a jump squat task resulted in improvements in 30m sprint time (34). The improved running performance in the Randell et al (2011) study could be attributed to 1) the inclusion of jump squats in the training program, or 2) the concurrent exposure of athletes to running stimulus during the training program (34). During the present study participants did not participant in any running sessions or jump squat training. It is possible that the training stimulus was not specific enough to transfer to sprint and acceleration tasks. However, the increased strength and power abilities observed demonstrate increased physical potential which may be transferable to speed and acceleration tasks in the context of more specific training.

It is interesting to consider why the subjective and objective condition responses were so different. The research design matched the training prescription between groups by utilizing equivalent intensity descriptors, which theoretically should have resulted in similar training intensities and responses in both groups. Assessment of volume load indicated that the total weight lifted across conditions was the same. A plausible explanation is the motivational effect of immediate objective feedback on each lift. Velocity-based feedback has been shown to acutely increase movement velocity within resistance training sessions, as a result of increased participant motivation (44). In addition, feedback has also been shown to result in improved training adaptations over a four-week training period (43). Based on these findings it is possible that in this study, participants trained with greater intent under the objective condition due to the motivational effects of the feedback received. This assertion will need to be empirically assessed in future in a trial that utilizes velocity for prescription but blinds the participants to the feedback.

A strength of this study was the use of a randomized cross over design. This is a more robust experimental method than those used previously (9,18,27) because it reduces the effect of variability between the groups by exposing all participants to both experimental conditions. Despite this strong design, the study was still subject to some limitations. Foremost among these is the absence of a "washout" period between exposure to the two experimental conditions. Further, the periodization structure (maximal strength vs strength-speed) was changed when participants swapped conditions. These limitations were due to the constraints of performing research within an applied setting, where the study duration was curtailed by the start of preseason fixtures, and periodization had to progress in order to prepare participants for the upcoming season. Within these constraints, it is possible that an ordering effect could have occurred with one group benefitting from experiencing the objective training prior to the subjective condition, or benefitting from receiving velocity feedback during the strength-speed phase. While the possibility of ordering effects should be noted, there were no statistical or practical differences observed between trial arms. A further limitation is that the objective and subjective intensity prescriptions were derived from previously published data rather than being determined within the participant group. This approach was in accordance with previous research (9), and likely reflects how coaches prescribe training velocities in practical settings (26) but may not be the most accurate approach. Recently it has been shown that VBT devices cannot be used interchangeably (30), and since the data that the intensity prescriptions were determined from used different devices (6,15,37,38,46) this represents a source of inaccuracy in the prescription. Ideally, researchers and practitioners should construct individual load velocity profiles for each exercise prescribed (12) using the devices available within their program (30). This is a highly time intensive process but would likely increase the accuracy of training prescription greatly. In light of these limitations, the promising results presented here should be viewed with some caution. The empirical methods can be significantly improved, but the results are likely representative of how autoregulation methodologies are used in applied settings and as such have a degree of ecological validity.

PRACTICAL APPLICATIONS

The results of this study demonstrate that autoregulatory training prescription leads to improvements in physical performance. Both objective (VBT) and subjective (perception of effort) autoregulation methods were shown to be effective for enhancing strength and power in this study, but the objective approach resulted in larger improvements. This suggests that if the technology is available, objective velocity-based methods are preferable for guiding autoregulatory training prescription. This research will inform practitioner choices for the implementation of autoregulation based on the resources available in their training environment.

REFERENCES

1. Abe T, DeHoyos DV, Pollock ML and Garzarella L. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *Eur J Appl Physiol* 81:174-80, 2000.

2. Balsalobre-Fernandez C, Glaister M and Lockey R. The validity and reliability of an iphone app for measuring vertical jump performance. *J Sport Sci* 33:1574-9, 2015.

3. Balsalobre-Fernández C, Kuzdub M, Poveda-Ortiz P and Campo-Vecino JD. Validity and reliability of the PUSH^{TM} wearable device to measure movement velocity during the back squat exercise. *J Strength Cond Res* 30:1968-74, 2016.

4. Banyard HG, Tufano JJ, Delgado J, Thompson SW and Nosaka K. Comparison of the effects of velocity-based training methods and traditional 1RM-percent-based training prescription on acute kinetic and kinematic variables. *Int J Sports Physiol Perform* 14:246-55, 2019.

5. Bompa O and Haff G. Periodization: Theory and methodology of training. 5 ed. Human Kinetics; 2009.

6. Bosco C, Belli A, Astrua M, et al. A dynamometer for evaluation of dynamic muscle work. *Eur J Appl Physiol Occup Physiol* 70:379-86, 1995.

7. Conceição F, Fernandes J, Lewis M, Gonzaléz-Badillo JJ and Jimenéz-Reyes P. Movement velocity as a measure of exercise intensity in three lower limb exercises. *J Sports Sci* 34:1099-106, 2016.

8. Darrall-Jones JD, Jones B, Roe G and Till K. Reliability and usefulness of linear sprint testing in adolescent rugby union and league players. *J Strength Cond Res* 30:1359-64, 2016.

9. Dorrell HF, Smith MF and Gee TI. Comparison of velocity-based and traditional percentage-based loading methods on maximal strength and power adaptations . *J Strength Cond Res*, 2019 [Epub ahead of print] doi: 10.1519/JSC.0000000000003089.

10. Earp JE and Newton RU. Advances in electronic timing systems: Considerations for selecting an appropriate timing system. *J Strength Cond Res*, 26:1245-1248, 2012

11. Enoka RM and Duchateau J. Muscle fatigue: What, why and how it influences muscle function. *J Physiol* 586:11-23, 2008.

12. Fahs CA, Blumkaitis JC and Rossow LM. Factors related to average concentric velocity of four barbell exercises at various loads. *J Strength Cond Res* 33:597-605, 2019.

13. Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. *Sports Med* 34:663-79, 2004.

14. Gearhart J, Lagally K, Riechman S, Andrews R and Robertson R. Strength tracking using the OMNI resistance exercise scale in older men and women. *J Strength Cond Res* 23:1011-15, 2009.

15. González-Badillo JJ and Sánchez-Medina L. Movement velocity as a measure of loading intensity in resistance training. *Int J Sports Med* 31:347-52, 2010.

16. Haff GG and Triplett TN. Essentials of strength training and conditioning. Champagne, IL: Human Kinetics; 2015.

17. Helms ER, Cross MR, Brown SR, Storey A, Cronin J and Zourdos MC. Rating of perceived exertion as a method of volume autoregulation within a periodized program. *J Strength Cond Res* 32:1627-36, 2018.

18. Helms ER, Byrnes RK, Cooke DM, et al. RPE vs. Percentage 1RM loading in periodized programs matched for sets and repetitions. *Front Physiol* 9:247, 2018.

19. Hickson RC, Hidaka K, Foster C, Falduto MT and Chatterton RT. Successive time courses of strength development and steroid hormone responses to heavy-resistance training. *J Appl Physiol* 76:663-70, 1994.

20. Hopkins WG, Marshall SW, Batterham AM and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41:3-13, 2009.

21. Hughes LJ, Banyard HG, Dempsey AR, Peiffer JJ and Scott BR. Using load-velocity relationships to quantify training-induced fatigue. *J Strength Cond Res* 33:762-73, 2019.

22. Jovanović M and Flanagan EP. Researched applications of velocity based strength training. *J Aust Strength Cond* 22:58-69, 2014.

23. Kiely J. Periodization paradigms in the 21st century: Evidence-led or tradition-driven? *Int J Sports Physiol Perform* 7:242-50, 2012.

24. Kraemer WJ and Ratamess NA. Fundamentals of resistance training: Progression and exercise prescription. *Med Sci Sports Exerc* 36:674 - 88, 2004.

25. Leveritt M and Abernethy PJ. Effects of carbohydrate restriction on strength performance. *J Strength Cond Res* 13:52-7, 1999.

26. Mann B, Ivey P and Sayers S. Velocity-Based training in football. *Strength and Conditioning Journal* 37:10-20, 2015.

27. Mann JB, Thyfault JP, Ivey PA and Sayers SP. The effect of autoregulatory progressive resistance exercise vs. Linear periodization on strength improvement in college athletes. *J Strength Cond Res* 24:1718-23, 2010.

28. Mann JB, Bryant KR, Johnstone B, Ivey PA and Sayers SP. Effect of physical and academic stress on illness and injury in division 1 college football players. *J Strength Cond Res* 30:20-5, 2016.

29. McMaster DT, Gill ND, Cronin JB and McGuigan MR. Force-Velocity-Power assessment in semiprofessional rugby union players. *J Strength Cond Res* 30:1118-26, 2016.

30. Mitter B, Hölbling D, Bauer P, Stöckl M, Baca A and Tschan H. Concurrent validity of field-based diagnostic technology monitoring movement velocity in powerlifting exercises. *J Strength Cond Res*, 2019. [Epub ahead of print] doi: 10.1519/JSC.0000000000003143

31. Nevin MJ. Auto-Regulated resistance training: Does velocity-based training represent the future? *Strength & Conditioning Journal*, 2019. [Epub ahead of print] doi: 10.1519/SSC.0000000000000471

32. Niewiadomski W, Laskowska D, Gasiorowska A, Cybulski G, Strasz A and Langfort J. Determination and prediction of one repetition maximum (1RM): Safety considerations. *Journal of Human Kinetics* 19:109-19, 2008.

33. Pareja-Blanco F, Rodríguez-Rosell D, Sánchez-Medina L, Gorostiaga E and González-Badillo J. Effect of movement velocity during resistance training on neuromuscular performance. *Int J Sports Med* 35:916-24, 2014.

34. Randell AD, Cronin JB, Keogh JW, Gill ND and Pedersen MC. 2011. Effect of instantaneous performance feedback during 6 weeks of velocity-based resistance training on sport-specific performance tests. *J Strength Cond Res*, 25:87-93, 2011.

35. Reilly T and Piercy M. The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics* 37:107-15, 1994.

36. Sánchez-Medina L and González-Badillo JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Med Sci Sports Exerc* 43:1725-34, 2011.

37. Sánchez-Medina L, González-Badillo JJ, Pérez CE and Pallarés JG. Velocity- and power-load relationships of the bench pull vs. Bench press exercises. *Int J Sports Med* 35:209-16, 2014.

38. Sánchez-Medina L, Pallarés JG, Pérez CE, Morán-Navarro R and González-Badillo JJ. Estimation of relative load from bar velocity in the full back squat exercise. *Sports Med Int Open* 1:E80 - 8, 2017.

39. Suchomel T, Comfort P and Lake J. Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength and Conditioning Journal* 39,10-20 2017.

40. Suchomel TJ, Nimphius S and Stone MH. The importance of muscular strength in athletic performance. *Sports Med* 46:1419-49, 2016.

41. Sweet TW, Foster C, McGuigan MR and Brice G. Quantitation of resistance training using the session rating of perceived exertion method. *J Strength Cond Res* 18:796-802, 2004.

42. Tan B. Manipulating resistance training program variables to optimize maximum strength in men: A review. *J Strength Cond Res* 13:289-304,1999.

43. Weakley J, Ramirez-Lopez C, McLaren S, et al. The effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics during the barbell back squat. *Int J Sports Physiol Perform*, 2019. [Epub ahead of print] doi: 10.1123/ijspp.2018-1008

44. Weakley JJS, Till K, Darrall-Jones J, et al. The influence of resistance training experience on the between-day reliability of commonly used strength measures in male youth athletes. *J Strength Cond Res* 31:2005-10, 2017.

45. Wong del P, Ngo KL, Tse MA and Smith AW. Using bench press load to predict upper body exercise loads in physically active individuals. *J Sports Sci Med* 12:38-43, 2013.

46. Zourdos MC, Klemp A, Dolan C, Quiles JM, Schau KA, Jo E, Helms E, Esgro B, Duncan S, Garcia Merino S and Blanco R. Novel resistance training-specific rating of perceived exertion scale measuring repetitions in reserve. *J Strength Cond Res* 30:267-75, 2016.

Table 1 – Descriptive characteristics and randomised group comparisons of participants prior to training program participation.

	All players	Group 1	Group 2	Difference between groups
Age (years)	22 ± 3	22 ± 3	23 ± 3	*unclear* (0.27, ±0.71)
Body Mass (kg)	94.3 ± 15.5	93.1 ± 14.5	95.6 ± 16.8	*unclear* (0.14, ±0.75)
CMJ (cm)	40.1 ± 7.1	42.5 ± 7.8	39.3 ± 6.3	*unclear* (0.41, ±0.69)
Back Squat (kg)	145 ± 25	137 ± 23	153 ± 27	*Likely moderate* (0.53, ±0.68)
Bench Press (kg)	109 ± 20	102 ± 20	116 ± 17	*Likely moderate* (0.64, ±0.61)
Chin ups (N)	10 ± 7	9 ± 7	12 ± 7	*unclear* (0.23, ±0.71)
10 m (sec)	1.74 ± 0.08	1.72 ± 0.07	1.75 ± 0.08	*unclear* (0.45, ±0.82)
20 m (sec)	2.99 ± 0.17	2.95 ± 0.16	3.04 ± 0.18	*unclear* (0.50, ±0.74)
40 m (sec)	5.35 ± 0.28	5.30 ± 0.26	5.41 ± 0.29	*unclear* (0.37, ±0.76)

Note: Data presented as mean ± SD. CMJ – Counter movement jump. Group differences are a statement of the likelihood and magnitude of effects (Effect size, ± 90%CI). Effect sizes were rated as trivial (<0.2), small (0.20-0.59), moderate (0.60-1.19), large (1.20-1.99) or very large (>2.0). Where the 90% confidence interval (CI) crosses both the upper and lower boundaries of the SWC (ES ± 0.2), the magnitude of change was described as unclear. Likelihood for substantial effects are described as almost certainly not (<0.5%), unlikely (5-25%), possibly (25-75%), likely (75-95%), very likely (95-99.5%) and most likely (>99.5%).

Table 2 – Equivalent resistance training intensity prescriptions utilising traditional percentage-based, perception of effort and velocity-based descriptors.

	Intensity prescription					
Targeted strength quality	Traditional	Perceived effort		Velocity-based (m/s)		
	% of 1RM	RIR	RPE	Lower body	Upper body push	Upper body pull
Maximal Strength Sets 2 – 8 Reps < 6	100	Maximum Effort	10	< 0.55	< 0.3	< 0.65
	95	No further reps, but could increase load	9.5	< 0.55	< 0.3	< 0.65
	90	1	9	< 0.55	< 0.4	< 0.65
	85	1–2	8.5	0.55 – 0.75	< 0.4	0.65 – 0.95
Strength-Speed Sets 3 – 6 Reps 2 - 5	80	2	8	0.65 – 0.75	0.4 – 0.65	0.65 – 0.95
	75	2–3	7.5	0.75 – 0.85	0.4 – 0.65	0.65 – 0.95
	70	3	7	0.85 – 0.95	0.4 – 0.65	0.95 – 1.25
	65	4-6 reps remaining	6.5	0.95 – 1.0	0.65 – 0.95	0.95 – 1.25
	60	4-6 reps remaining	6	1.0 – 1.1	0.65 – 0.95	0.95 – 1.25
Speed-Strength Sets 2 – 5 Reps 3 - 6	55	4-6 reps remaining	5	> 1.1	0.9 – 1.3	1.25 – 1.5
	50	4-6 reps remaining	5	> 1.1	0.9 – 1.3	1.25 – 1.5
	45	Light effort	4	> 1.1	0.9 – 1.3	1.25 – 1.5
	40	Light effort	4	> 1.1	0.9 – 1.3	> 1.5
	35	Light effort	3	> 1.1	0.9 – 1.3	> 1.5
	30	Light effort	3	> 1.1	0.9 – 1.3	> 1.5

Intensity descriptors are from previously reported studies, (6,15,37,46)

Table 3 – Training program for maximal strength training block including objective (velocity-based) and subjective (perception of effort) intensity descriptors.

Day	Exercise	Sets	Reps	Intensity				Rest (sec)
				Traditional (% of 1RM)	Velocity ($m.sec^{-1}$)	Perception of effort		
						RPE	RIR	
1	Back squat	8	3	85 - 90	0.65 – 0.95	8.5 - 9	1 - 2	90 – 120
	Bent over row	8	3	85 - 90	< 0.65	8.5 - 9	1 - 2	90 – 120
	Shoulder press	8	3	85 - 90	< 0.40	8.5 - 9	1 - 2	90 – 120
2	Underhand pull ups	8	3	85 - 90	< 0.65	8.5 - 9	1 - 2	90 – 120
	Incline bench press	8	3	85 - 90	< 0.40	8.5 - 9	1 - 2	90 – 120
	DB shoulder press	8	3	85 - 90	< 0.40	8.5 - 9	1 - 2	90 – 120
3	Dead lift	8	3	85 - 90	< 0.55	8.5 - 9	1 - 2	90 – 120
	Wide grip pull ups	8	3	85 - 90	< 0.65	8.5 - 9	1 - 2	90 – 120
	Push press	8	3	85 - 90	< 0.40	8.5 - 9	1 - 2	90 – 120
4	Bench Press	8	3	85 - 90	< 0.40	8.5 - 9	1 - 2	90 – 120
	Single arm dumbbell row	8	3 EA	85 - 90	< 0.65	8.5 - 9	1 - 2	90 – 120
	Dumbbell lateral raise	8	3	85 - 90	< 0.65	8.5 - 9	1 - 2	90 – 120

Table 4 – Training program for strength speed training block including objective (velocity-based) and subjective (perception of effort) intensity descriptors.

Day	Exercise	Sets	Reps	Intensity				Rest (sec)
				Traditional (% of 1RM)	Velocity ($m.sec^{-1}$)	Perception of effort		
						RPE	RIR	
1	Hex bar dead lift	6	4	70 - 80	0.65 – 0.95	7 - 8	2 - 3	120
	Under hand pull up	6	4	70 - 80	0.65 – 1.25	7 - 8	2 - 3	120
	Bench press	6	4	70 - 80	0.40 – 0.65	7 - 8	2 - 3	120
	Push press	6	4	70 - 80	0.65 – 0.95	7 - 8	2 - 3	120
2	Lunges	6	4 EL	70 - 80	0.65 – 0.95	7 - 8	2 - 3	120
	Incline bench press	6	4	70 - 80	0.40 – 0.65	7 - 8	2 - 3	120
	Bent over row	6	4	70 - 80	0.65 – 1.25	7 - 8	2 - 3	120
	Seated shoulder press	6	4	70 - 80	0.40 – 0.65	7 - 8	2 - 3	120
3	Box squat	6	4	70 - 80	0.65 – 0.95	7 - 8	2 - 3	120
	Wide grip pull ups	6	4	70 - 80	0.65 – 1.25	7 - 8	2 - 3	120
	Bench press	6	4	70 - 80	0.40 – 0.65	7 - 8	2 - 3	120
	½ kneeling single arm dumbbell shoulder press	6	4 EA	70 - 80	0.40 – 0.65	7 - 8	2 - 3	120

Table 5 - Changes in physical performance measures achieved through an autoregulatory training program guided by either subjective (perception of effort) or objective (velocity) feedback.

	Performance change (% changes, ±90%CI)		**Difference between conditions – (Hedges' *g* [90% Confidence limits])**
	Objective	Subjective	
Counter movement jump	↑ 8.2, ±1.1%* *Almost certainly*	↑ 3.8, ±0.9%*# *Likely*	1.78 [95%CI 1.10, 2.37] *Almost certainly* large
Back Squat	↑ 7.5, ±1.5%* *Almost certainly*	↑ 3.5, ±0.8%*# *Possibly*	1.37 [95%CI 0.77, 1.92] *Almost certainly* large
Bench Press	↑ 7.7, ±2.1%* *Almost certainly*	↑ 3.8, ±0.9%*# *Likely*	0.98 [95%CI 0.33, 1.49] *Very likely* medium
10m time	↓ 0.4, ±0.4% *Almost certainly trivial*	↑ 0.5, ± 0.3%* *Almost certainly trivial*	0.82 [95%CI 0.12, 1.51] *Very likely* medium

20m time	↓ 0.4, ±0.2% *Almost certainly trivial*	↓ 0.1, ±0.3%[#] *Almost certainly trivial*	0.49 [95%CI -0.27, 1.22] *Unclear*
40m time	↓ 0.4, ±0.3%* *Almost certainly trivial*	↓ 0.1, ±0.2%[#] *Almost certainly trivial*	0.76 [95%CI 0.14, 1.29] *Very likely* medium

* indicates a significant change across the time period of the training program. # indicates a significant difference between groups. *Italic* statements describe the likelihood for meaningful effects - *almost certainly not (<0.5%), unlikely (5-25%), possibly (25-75%), likely (75-95%), very likely (95-99.5%) and most likely (>99.5%). Difference between conditions are statements of the likelihood and magnitude of effects (Effect size, ± 90%CI). Hedges' g effect sizes were rated as trivial (<0.2), small (0.20-0.59), moderate (0.60-1.19), large (1.20-1.99) or very large (>2.0). Where the 90% confidence interval (CI) crosses both the upper and lower boundaries of the SWC (ES ± 0.2), the magnitude of change was described as unclear.*

Figures

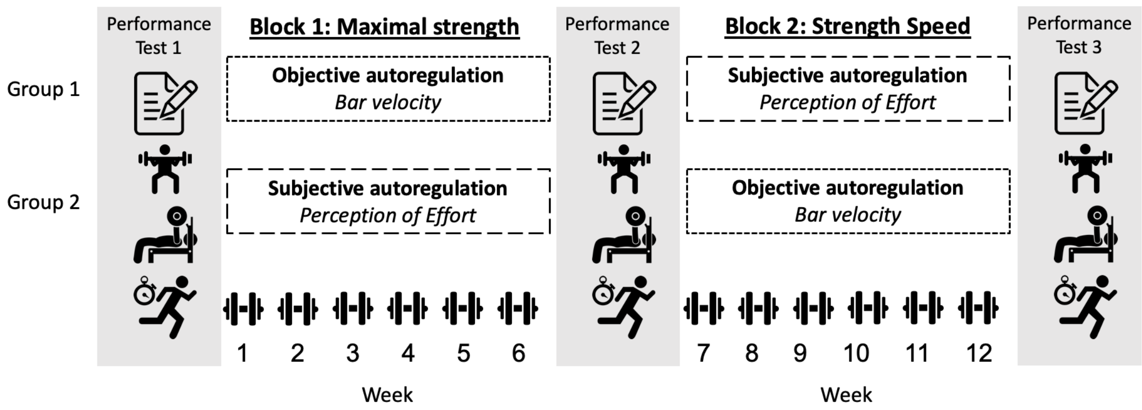

Figure 1 – Schematic representation of the study protocol illustrating the randomised cross over design.

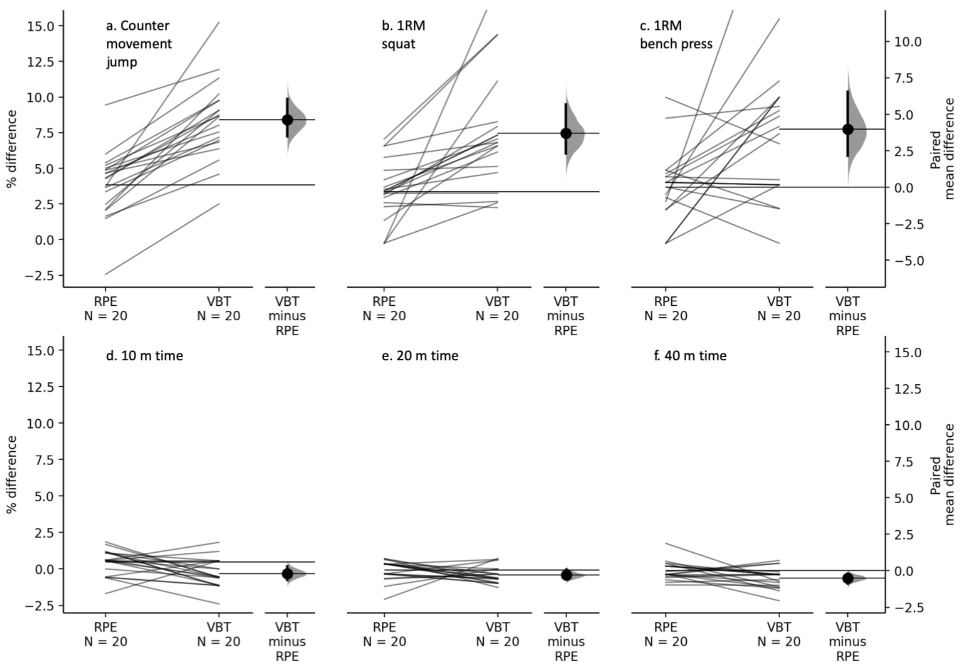

Figure 2 - The difference in training response (% change) to subjective (RPE) and objective (VBT) training prescription is shown in the above Gardner-Altman estimation plots. Both groups are plotted on the left axes as a slopegraph: each paired set of observations is connected by a line. The paired mean difference is plotted on a floating axes on the right as a bootstrap sampling distribution. The mean difference is depicted as a dot; the 90% confidence interval is indicated by the ends of the vertical error bar. Panels a, b, c, d, e and f indicate response to different performance tests.