Communications in Kinesiology

Research

DOI:
10.51224/cik.2024.69

Subject Areas:
Training and Performance Analysis

Keywords:
Resistance training, strength training, velocity-based training, fatigue, training load

Editor:
Andy Hall

STORK
SOCIETY FOR TRANSPARENCY OPENNESS AND REPLICATION IN KINESIOLOGY

Acute effects of using individual velocity targets to regulate resistance training load

Samuel T. Orange[1,2,*], Connor Guerin[2], Cameron Taylor[2], Louis Poole[2], Kathleen Sanger[2], Sam Clarke[2], Leah Goodley[2], Charlie Bradbury[2], and Will Pearmain[2]

[1]Newcastle University Centre for Cancer, Newcastle University, Newcastle upon Tyne, UK
[2]School of Biomedical, Nutritional and Sport Sciences, Faculty of Medical Sciences, Newcastle University, Newcastle upon Tyne, UK
[*]Correspondence: sam.orange@ncl.ac.uk

We determined the acute biomechanical, physiological, and perceptual effects of using individualised velocity targets (IVT) or a percentage of one repetition maximum (%1RM) to regulate resistance training load. Thirty-nine resistance-trained adults (age: 21.8±3.2 years) completed two strength training sessions (five sets of five free-weight back squats) in a randomised, counterbalanced order. The %1RM session involved using a fixed load at 80% 1RM, whereas the IVT session used a modifiable load corresponding to the mean velocity at 80% 1RM. Kinetic and kinematic data and rating of perceived exertion (RPE) were recorded during training sessions. Countermovement jump (CMJ) height and blood lactate concentration were measured pre- and post-session, and perceived muscle soreness and fatigue were measured 24-hours post-exercise using 10-point Likert scales. We used null-hypothesis significance testing to test for differences between conditions and two one-sided tests (TOST) to assess equivalence. IVT significantly increased sessional mean velocity (mean difference=0.05 $\text{m}\cdot\text{s}^{-1}$), peak velocity (0.08 $\text{m}\cdot\text{s}^{-1}$), mean power (54.4 W), and peak power (141 W), while significantly reducing barbell load (-2.7 kg), RPE (-0.49), time under tension (-0.13 s), and velocity loss (0.02 $\text{m}\cdot\text{s}^{-1}$), compared to %1RM. IVT and %1RM had equivalent effects on post-exercise perceived fatigue (0.11, 10-point-scale) and pre-post changes in blood lactate (-0.50 mmol/L) and CMJ height (-0.75 cm). In conclusion, using individualised velocity targets to regulate resistance training load increases movement velocity in repeated sets of free-weight back squats but does not meaningfully influence markers of post-exercise fatigue compared to %1RM.

Introduction

There are several approaches that can be used to prescribe resistance training load. A common method is to use a percentage of one repetition maximum (%1RM) combined with a predetermined number of repetitions (Suchomel et al., 2021). However, this approach has been criticised because it does not account for daily fluctuations in an individual's physical performance capability (Scott et al., 2016). Maximum strength can fluctuate from day-to-day or change throughout a training block. Additionally, the ability to complete repetitions at a given %1RM varies significantly between individuals and across different exercises (Richens & Cleather, 2014; Shimano et al., 2006). Consequently, prescribing resistance training load based on %1RM may result in a load that is either too light or too heavy for the intended training outcome, potentially leading to suboptimal adaptations.

Alternative methods of monitoring and prescribing resistance training load, such as using rating of perceived exertion (RPE) or repetitions in reserve, can account for an individual's perceived performance capability on a given day (Greig et al., 2020). However, these methods rely on an individual's ability to predict proximity to repetition failure, which is often inaccurate (Halperin et al., 2021). Velocity-based training (VBT) uses instantaneous velocity feedback to objectively monitor and adjust resistance training load (Orange, Metcalfe, Robinson, et al., 2020). Movement velocity and barbell load are inversely related (Orange, Metcalfe, Marshall, et al., 2020; Sánchez-Medina et al., 2017), and changes in velocity against a given load reflect changes in an individual's performance capacity. Thus, velocity feedback may be used to objectively manipulate resistance training load according to an individual's current physiological state (e.g., the individual's level of fatigue on a given day).

Many approaches exist within the VBT paradigm, including the prediction of 1RM strength from velocity obtained against submaximal loads, using relative velocity loss thresholds to manage fatigue, and prescribing individualised velocity targets (IVT) to target components of the load-velocity relationship (Balsalobre-Fernández & Torres-Ronda, 2021). As one of the most established VBT approaches, IVT involves completing a set of repetitions at a concentric mean velocity that falls within a pre-defined, individually-tailored threshold (e.g., 0.55 to 0.65 $\text{m} \cdot \text{s}{-1}$) (Orange et al., 2022). Using IVT to prescribe resistance training load has potential to alter the acute biomechanical, physiological, and perceptual responses to resistance exercise (Banyard et al., 2019; Orange, Metcalfe, Robinson, et al., 2020), and hence the time course of post-exercise recovery and resulting training adaptations (Balshaw et al., 2016). In a randomised trial with 27 academy rugby league players, we previously reported higher concentric movement velocity and power, and lower RPE and time under tension, in the free-weight back squat when training load was adjusted using IVT compared to using a fixed load based on %1RM, which led to superior velocity-specific adaptations following a 7-week intervention (Orange, Metcalfe, Robinson, et al., 2020). In a cross-sectional study with 15 resistance-trained men, Banyard and colleagues also showed that back squat movement velocity was greater when using IVT compared to %1RM (Banyard et al., 2019). Additionally, the decline in movement velocity across repeated sets of back squats highly correlates with greater post-exercise blood lactate concentration and reductions in countermovement jump (CMJ) height (Sanchez-Medina & Gonzalez-Badillo, 2011). However, no study has tested for equivalence in training responses between IVT and %1RM. This means that it is not known whether differences in acute biomechanical, physiological, and perceptual responses between these two resistance training approaches are large enough to be considered important (Lakens, 2017). Additionally, no study has tested whether using IVT to regulate resistance training load influences the extent of post-exercise fatigue, which has important implications for ensuring preparedness for repeated training exposure (Dambroz et al., 2021).

Therefore, the purpose of this study was to compare effects of using IVT or %1RM on the acute biomechanical, physiological, and perceptual responses to free-weight resistance exercise in resistance-trained adults. We hypothesized that IVT would increase concentric movement velocity in the back squat compared to %1RM. We combined null-hypothesis significance testing with the two one-sided tests (TOST) procedure to identify differences between IVT and %1RM and determine whether those differences were large enough to be considered meaningful.

Methods

Participants

Thirty-nine resistance-trained adults participated in this study (Table 1). Eligibility criteria were: (i) aged 18 to 40 years; (ii) participating in resistance exercise, including the free-weight back squat exercise, on at least one day per week for the last 6 months; and (iii) able to give written informed consent. Main exclusion criteria were: (i) known pre-existing cardiovascular, metabolic, or renal disease; (ii) resting hypertension; and (iii) any injury, physical disability, or cognitive impairment that may contraindicate exercise. The study was approved by the Faculty of Medical Sciences Research Ethics Committee at Newcastle University. All participants provided written informed consent before taking part and were able to withdraw at any point without giving a reason or without any negative consequences. The study protocol was prospectively registered on Open Science Framework (https://osf.io/kdnuy).

Table 1. Participant characteristics

	Female (n=12)	Male (n=27)	Total (n=39)
Age (years)	22.3 ± 4.8	21.5 ± 2.1	21.8 ± 3.2
Body mass (kg)	73.3 ± 16.4	83.5 ± 10.4	80.4 ± 13.2
Height (cm)	167 ± 9.0	183 ± 7.0	178 ± 10.8
BMI (kg/m^2)	26.3 ± 5.1	25.0 ± 2.1	25.4 ± 3.3
Ethnicity			
White	11 (92%)	26 (96%)	37 (95%)
Asian British	1 (8%)	0 (0%)	1 (3%)
Black British	0 (0%)	1 (4%)	1 (3%)
1RM (kg)	96.5 ± 21.1	131 ± 24.0	121 ± 28.1
1RM relative to body mass	1.3 ± 0.24	1.6 ± 0.22	1.5 ± 0.25
Resistance training experience (years)	3.7 ± 3.0	5.0 ± 2.9	4.6 ± 2.9

Experimental Design

This study used a randomised, counterbalanced, crossover design. Participants made four separate visits to the Biomechanics Laboratory at Newcastle University, separated by a minimum of 72 hours. In the first visit, participants performed a 1RM assessment in the free-weight back squat. The second visit involved an incremental loading test in the back squat. In visits three and four, participants completed two strength training sessions in a randomised, counterbalanced order, using either a modifiable load based on individualised velocity targets (IVT session), or a fixed load based on a percentage of 1RM (%1RM session). Before each visit, participants were instructed to avoid lower-body resistance exercise for 72 hours, refrain from caffeine intake for 12 hours, and to maintain usual dietary habits. Pre-session countermovement jump (CMJ) height was statistically equivalent between strength training sessions (%1RM = 34.8 ± 7.9 cm; IVT = 34.6 ± 7.0 cm, equivalence p-value = 0.001), suggesting participants attended sessions in a similar physical condition.

Randomisation

The randomisation sequence was generated in block sizes of six by an independent researcher using online randomisation software (https://www.sealedenvelope.com). The sequence was concealed from participants until the first two laboratory visits were complete.

1RM Assessment

The 1RM protocol for the free-weight back squat has been described previously(Orange et al., 2019; Orange, Metcalfe, Marshall, et al., 2020). Briefly, participants performed a standardised warm-up consisting of 5 minutes stationary cycling, dynamic stretching, and five body weight squats. The same standardised warm-up was undertaken at the beginning of each subsequent visit to the laboratory. Participants then performed five free-weight back squat repetitions at ~50% of their estimated 1RM, followed by three repetitions at ~70% 1RM and two repetitions at ~80% 1RM. Thereafter, participants performed 1RM attempts with progressively increased loads. Participants were required to achieve a parallel squat depth (thigh parallel to the floor), which was monitored by a research team member, to maintain constant downward force on the barbell so it did not leave the shoulders, and to keep their feet in contact with the floor during all repetitions. Back squats were performed with an Olympic barbell (Eleiko, Halmstad, Sweden) placed in a high-bar position inside an adjustable power rack (Perform Better Ltd, Southam, UK). A maximum of five attempts were permitted, with three minutes of passive rest in between attempts, and the last successful lift was taken as the 1RM. Participants were provided with strong verbal encouragement throughout.

Incremental Loading Test

Following the standardised warm-up, participants completed three free-weight back squat repetitions at 40% of 1RM established in the previous visit, three repetitions at 60% 1RM, two repetitions at 80% 1RM, and one repetition at 90% 1RM (Orange, Metcalfe, Robinson, et al., 2020). Participants were verbally encouraged to complete each repetition with maximal concentric velocity, but objective velocity feedback was not provided. Three minutes of passive rest were provided in between sets. A validated linear position transducer (GymAware PowerTool, Kinetic Performance Technologies, Canberra, Australia) was used to measure mean velocity in the concentric phase of each repetition (Banyard et al., 2017; Orange, Metcalfe, Robinson, et al., 2020). Load-velocity relationships were constructed for each participant by plotting mean velocity against load and applying a line of best fit (Banyard et al., 2019). The mean velocity corresponding to 80% 1RM based on the individual's linear regression equation was used to provide individualised velocity targets and modify training load in the IVT session.

Strength Training Sessions

In both training sessions, participants completed the standardised warm-up followed by five free-weight back squat repetitions at 50% 1RM, three repetitions at 60% 1RM, and three repetitions at 80% 1RM. All back squat repetitions were performed with a controlled, self-selected eccentric velocity until the thighs were parallel to the floor, which was monitored by a research team member and recorded with the linear position transducer. Squat depth was statistically equivalent between training sessions (%1RM: 0.56 ± 0.10 cm; IVT 0.55 cm ± 0.10 cm, equivalence p-value = 0.035). Participants performed the concentric portion of each repetition as quickly as possible with the aid of strong verbal encouragement. Participants did not have access to velocity feedback in either session because feedback in and of itself can influence training outcomes (Weakley et al., 2023). Three minutes of passive rest were provided between sets. Participants were allowed to wear weightlifting equipment (e.g., belt) if this was consistent in both training sessions.

Percentage of 1RM

Participants completed five sets of five repetitions in the free-weight back squat with a fixed load of 80% 1RM. This load was chosen because 80% 1RM is often prescribed in strength programmes, velocity data obtained at this load is reliable, and it aligns with previous research (Banyard et al., 2019; Orange, Metcalfe, Marshall, et al., 2020; Orange, Metcalfe, Robinson, et al., 2020).

Individualised velocity targets

For the IVT session, participants completed five sets of five repetitions in the free-weight back squat with a load that corresponded to mean velocity at 80% 1RM established from the incremental loading test. If the mean velocity (average of the warm-up repetitions) during the final warm-up set at 80% 1RM was ±0.06 $\mathrm{m \cdot s^{-1}}$ outside the target movement velocity, then the barbell load was adjusted by ±5%

1RM for the first "working" set (to the nearest 2.5 kg). Otherwise, the barbell load for the first set was maintained at 80% 1RM. Thereafter, if the (average) mean velocity in a set of five repetitions was ±0.06 $m \cdot s^{-1}$ outside the target movement velocity, the barbell load was then adjusted by ±5% 1RM for the subsequent set. A threshold of ±0.06 $m \cdot s^{-1}$ was chosen based on the magnitude of measurement error in mean velocity (Orange, Metcalfe, Marshall, et al., 2020) and to align with previous research (Banyard et al., 2019; Orange et al., 2021).

Outcomes

Biomechanical outcomes

A linear position transducer (GymAware PowerTool) was used to record kinetic and kinematic data in the concentric phase of each back squat repetition, including mean velocity ($m \cdot s^{-1}$), peak velocity ($m \cdot s^{-1}$), time under tension (s), mean power (W), peak power (W), peak force (N), and work (J). The GymAware PowerTool consists of a floor unit, made up of a spring-powered retractable cable that is wound on a cylindrical spool coupled to the shaft of an optical encoder. The floor unit was placed on the floor perpendicular to the right collar of the barbell. The other end of the cable was vertically attached to the barbell (immediately proximal to the right collar) using a Velcro strap. Vertical displacement of the barbell was measured from the rotational movement of the spool. The GymAware PowerTool also incorporates a sensor measuring the angle that the cable leaves the spool, which enables vertical-only displacement to be measured by correcting for any motion in the horizontal plane (using basic trigonometry). Displacement data were time-stamped at 20 millisecond time points to obtain a displacement-time curve for each repetition, which was down-sampled to 50 Hz for analysis. The sampled data were not filtered. The methods that the GymAware PowerTool uses to calculate kinetic and kinematic data have been described previously (Orange, Metcalfe, Liefeith, et al., 2020). Data were transmitted instantaneously via Bluetooth to a tablet (iPad, Apple Inc., California, USA) using the GymAware app and uploaded onto a cloud-based storage system. A member of the research team extracted mean velocity data from the app during the training sessions, while all other biomechanical data were extracted from the cloud-based storage system at a later date. The participant's body mass and the barbell load used were entered into the app prior to each set.

We manually calculated velocity loss within sets as the average difference in mean velocity between the first and last repetition within each set, and we calculated velocity loss across sets as the average difference in mean velocity between the first and fifth set. For the primary analysis, all biomechanical data were averaged across the 25 back squat repetitions to form a single score for each session. We further explored differences in mean velocity, mean velocity loss within sets, and barbell load in each individual set.

Physiological outcomes

Blood lactate concentration was measured as a marker of metabolic response. Capillary blood samples (20 μL) were collected following standard laboratory guidelines before each strength training session (prior to the warm-up) and after the final set (within 30 seconds of set completion) and analysed immediately for blood lactate (Biosen C-Line, EKF Diagnostics, Cardiff, UK).

Following the collection of the capillary blood sample, CMJ height was recorded as a measure of neuromuscular fatigue using the Optojump photocell system (Optojump, 144 Microgate, Bolzano, Italy), which samples at 1000 Hz and consists of two dual-beam bars (100 x 4 x 3 cm) that were placed in parallel approximately 1 m apart (Glatthorn et al., 2011). Participants placed their hands on their hips and descended downwards to a self-selected level before jumping upwards for maximum height. The pre-exercise CMJ test was completed prior to the warm-up and the post-exercise CMJ test was initiated within two minutes of completing the final set of back squats. Three CMJs were performed, with 60 seconds of rest in between, and the highest jump was used for analysis. The coefficient of variations for CMJ height were 4.4% for %1RM and 3.4% for IVT.

Perceptual outcomes

RPE was collected immediately after the completion of every set of back squats using the 1-10 OMNI-RES scale (Robertson et al., 2003). Specifically, participants were asked the same question at the end of each set: “how hard do you feel your muscles were working?”. Participants were initially familiarised with the OMNI-RES scale during the 1RM assessment, which was re-visited during the warm-up repetitions (i.e., back squat repetitions at 50, 60, and 80% 1RM) at the start of each training session. The scale remained in full view throughout the sessions. For our primary analysis, we calculated the mean RPE across sets to form a single score for each training session, and we additionally explored differences in RPE within each set.

Participants completed Likert scales for muscle soreness and overall fatigue 24-hours after completing each strength training session (Impellizzeri & Maffiuletti, 2007). The 10-point Likert scale for muscle soreness ranged from ‘no muscle soreness’ to ‘severe muscle soreness’, and the 10-point Likert scale for fatigue ranged from ‘no overall fatigue’ to ‘severe overall fatigue’. Participants were familiarised with the Likert scales and completed them via Google Forms (Google LLC, CA, USA) whilst in a seated, rested position.

Sample Size

Our primary outcome was difference in mean velocity between IVT and %1RM, and our goal was to obtain 80% power to reject the presence of an important difference between the two conditions (i.e., test for equivalence). We defined an important mean difference as 0.05 $\text{m} \cdot \text{s}^{-1}$ (i.e., equivalence bounds of -0.05 and 0.05 $\text{m} \cdot \text{s}^{-1}$) with an SD of 0.08 $\text{m} \cdot \text{s}^{-1}$, based on previous research showing that the measurement error in mean velocity is less than 0.05 $\text{m} \cdot \text{s}^{-1}$ and an increase in mean velocity of 0.05 $\text{m} \cdot \text{s}^{-1}$ in the back squat approximately represents a 5% increase in strength (Orange, Metcalfe, Marshall, et al., 2020; Sánchez-Medina et al., 2017). Given these parameters and an alpha level of 0.05, 22 participants were required to provide 80% power to reject an important difference using the TOST procedure. We initially recruited 20 participants from October 2021 to February 2022. To ensure we met our required sample size, we chose to hold another round of recruitment from October 2022 to February 2023, which led to an additional 19 participants, and 39 participants being recruited overall.

Statistical Analysis

We tested for differences and equivalence in outcomes between conditions. We used two-sided paired t-tests to test for non-zero differences between conditions, with the mean difference, 95% confidence interval, and p-value reported. We used the TOST procedure to test for equivalence; that is, to statistically reject the presence of effects large enough to be considered important (Lakens, 2017). For TOST, we reported the 90% confidence interval and the one-sided test with the highest p-value (Lakens, 2017). The TOST procedure requires stipulation of an upper and lower equivalence bound based on a minimum important difference. We considered a standardised effect size of Cohen's $d_z = 0.60$ to be the minimum important difference, based on: (i) it being approximately equal to the minimum important difference in mean velocity (0.05 ± 0.08 $\text{m} \cdot \text{s}^{-1}$) defined *a priori* to inform our sample size calculation, and (ii) standardised mean differences smaller than 0.60 corresponding with qualitative descriptions of “trivial” or “small” (Hopkins et al., 2009). Hence, if the entire width of the 90% confidence interval fell within equivalence bounds (d_z) of -0.60 and 0.60, the effect was considered equivalent between conditions. A conventional threshold of $p<0.05$ was used to denote statistical significance. All data were analysed in R version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). Data and code are available on Open Science Framework (https://osf.io/r5bgy).

Results

Biomechanical outcomes

Mean velocity in the back squat was significantly higher during the IVT session compared with the %1RM session (0.05 $m \cdot s^{-1}$, 95% CI: 0.03 to 0.06 $m \cdot s^{-1}$; Table 2). Peak velocity, mean power, and peak power attained in the back squat during the IVT session were significantly greater than during the %1RM session. In contrast, peak force and work were statistically equivalent between sessions (Table 2).

Table 2. Biomechanical, physiological, and perceptual outcomes in the IVT and %1RM training sessions

Outcome	n	%1RM*	IVT*	Mean Difference (95% CI)	p-NHST	p-TOST
Mean velocity ($m \cdot s^{-1}$)	39	0.46 ± 0.08	0.51 ± 0.07	0.05 (0.03 to 0.06)	<0.001	0.970
Peak velocity ($m \cdot s^{-1}$)	37[A]	0.90 ± 0.16	0.98 ± 0.16	0.08 (0.04 to 0.12)	<0.001	0.780
Velocity loss within sets ($m \cdot s^{-1}$)	39	-0.10 ± 0.05	-0.09 ± 0.04	0.02 (0.00 to 0.04)	0.037	0.061
Velocity loss across sets ($m \cdot s^{-1}$)	39	-0.04 ± 0.04	0.02 ± 0.07	0.06 (0.03 to 0.08)	<0.001	0.800
Barbell load (kg)	39	96.5 ± 22.4	93.8 ± 22.3	-2.7 (-3.8 to -1.7)	<0.001	0.910
Time under tension (s)	39	1.3 ± 0.23	1.2 ± 0.22	-0.13 (-0.18 to -0.07)	<0.001	0.780
Mean power (W)	35[AB]	747 ± 248	802 ± 262	54.4 (12.7 to 96.1)	0.012	0.188
Peak power (W)	35[AB]	1620 ± 582	1761 ± 659	141 (28.0 to 254)	0.016	0.159
Peak force (N)	35[AB]	2089 ± 592	2075 ± 588	-14.3 (-77.0 to 48.4)	0.650	0.002
Work (J)	35[AB]	952 ± 353	931 ± 353	-21.2 (-50.7 to 8.3)	0.153	0.022
CMJ height (cm)	39					
Pre		34.8 ± 7.9	34.6 ± 7.0			
Post		33.6 ± 7.3	32.6 ± 6.7			
Change		-1.2 ± 3.0	-2.0 ± 3.2	-0.75 (-1.6 to 0.10)	0.083	0.028
Blood lactate (mmol/L)	39					
Pre		2.0 ± 0.92	1.6 ± 0.94			
Post		5.4 ± 2.0	4.5 ± 2.0			
Change		3.4 ± 2.2	2.9 ± 1.7	-0.50 (-1.0 to 0.01)	0.052	0.045
RPE (0-10)	39	7.3 ± 1.1	6.8 ± 1.0	-0.49 (-0.77 to -0.21)	0.001	0.410
Soreness (0-10)	36[C]	5.5 ± 1.9	5.0 ± 1.9	-0.56 (-1.1 to 0.03)	0.060	0.053
Fatigue (0-10)	36[C]	4.7 ± 1.8	4.8 ± 1.7	0.11 (-0.41 to 0.63)	0.670	0.002

%1RM = percentage of 1RM; CMJ = countermovement jump; IVT = individualised velocity targets; RPE = rating of perceived exertion

[*] mean ± SD

[A] Data from n=2 participants were missing due to the data not being uploaded onto the cloud-based storage system.

[B] Data from n=2 participants were omitted from the analysis for these outcomes due to barbell load being incorrectly entered into the GymAware app.

[C] n=3 participants did not complete the Likert scales.

When broken down into individual sets, mean velocity in every set in the IVT session was significantly higher than the corresponding set in the %1RM session (Figure 1).

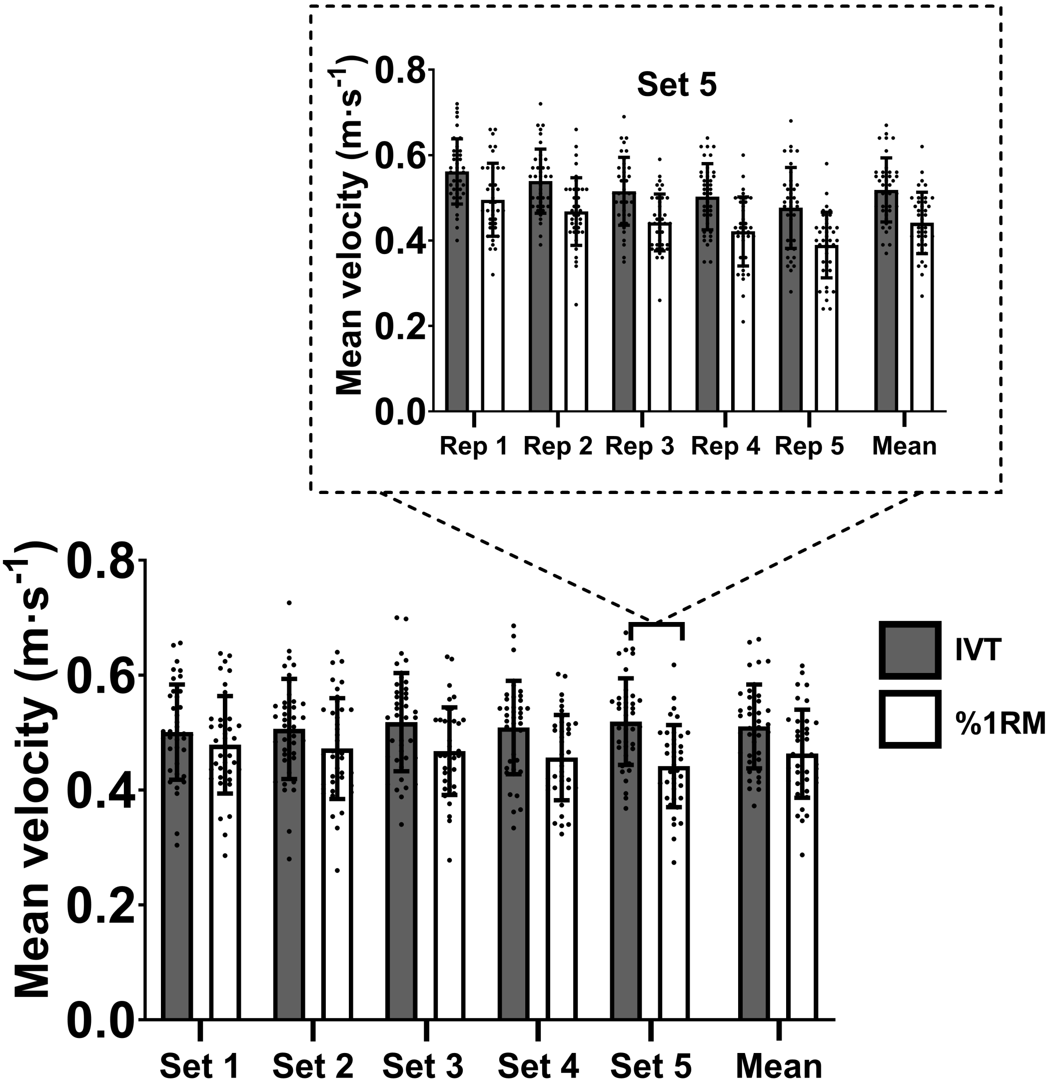

Figure 1: Mean velocity in the free-weight back squat during individualised velocity target (IVT) and percentage of one repetition maximum (%1RM) training sessions.

IVT prevented the loss in mean velocity across the training session (0.06 $m \cdot s^{-1}$, 95% CI: 0.03 to 0.08 $m \cdot s^{-1}$) and attenuated velocity loss within sets (0.02 $m \cdot s^{-1}$, 95% CI: 0.00 to 0.04 $m \cdot s^{-1}$). When individual sets were analysed separately, IVT minimised velocity loss within set 4 and set 5, whilst velocity losses within sets 1-3 were equivalent between IVT and %1RM sessions (Table 3).

There was an adjustment of barbell load for 22 out of 39 participants (56%) during the IVT training session. Of these, barbell load was reduced for 21 (54%) participants due to mean velocity in a set being ±0.06 $m \cdot s^{-1}$ below the individualised target velocity, while barbell load was increased for one (3%) participant due to mean velocity being ±0.06 $m \cdot s^{-1}$ above the target velocity. The mean barbell load in the IVT session was significantly lower than the barbell load in the %1RM session (-2.7 kg, 95% CI: -3.8 to -1.7 kg). When looking at individual sets, barbell load in set 1 was equivalent between sessions (0.5 kg, 95% CI: -1.0 to 0.02 kg), but barbell loads in sets 2 to 5 were significantly greater in the IVT session (Table 3).

Table 3. Mean velocity, velocity loss, barbell load, and RPE in each set of back squats in the IVT and %1RM training sessions (n=39).

Outcome		%1RM*	IVT*	Mean Difference (95% CI)	p-NHST	p-TOST
Mean velocity (m·s-1)						
	Set 1	0.48 ± 0.08	0.50 ± 0.08	0.02 (0.00 to 0.04)	0.021	0.093
	Set 2	0.47 ± 0.09	0.51 ± 0.09	0.03 (0.01 to 0.06)	0.005	0.230
	Set 3	0.47 ± 0.08	0.52 ± 0.09	0.05 (0.03 to 0.07)	<0.001	0.820
	Set 4	0.46 ± 0.07	0.51 ± 0.08	0.05 (0.02 to 0.08)	<0.001	0.870
	Set 5	0.44 ± 0.07	0.52 ± 0.08	0.08 (0.05 to 0.11)	<0.001	>0.999
Velocity loss (m·s-1)						
	Set 1	-0.09 ± 0.05	-0.09 ± 0.06	0.00 (-0.02 to 0.02)	0.870	<0.001
	Set 2	-0.09 ± 0.06	-0.09 ± 0.05	0.00 (-0.02 to 0.02)	0.810	0.001
	Set 3	-0.11 ± 0.08	-0.08 ± 0.07	0.03 (0.00 to 0.06)	0.080	0.030
	Set 4	-0.12 ± 0.09	-0.08 ± 0.06	0.03 (0.00 to 0.06)	0.028	0.076
	Set 5	-0.12 ± 0.08	-0.09 ± 0.06	0.03 (0.00 to 0.06)	0.034	0.064
Barbell load (kg)						
	Set 1	96.5 ± 22.4	96.0 ± 22.4	-0.5 (-1.0 to 0.02)	0.058	0.040
	Set 2	96.5 ± 22.4	94.5 ± 21.8	-2.1 (-3.0 to -1.1)	<0.001	0.790
	Set 3	96.5 ± 22.4	93.8 ± 22.5	-2.8 (-4.1 to -1.4)	<0.001	0.620
	Set 4	96.5 ± 22.4	92.8 ± 22.9	-3.7 (-5.3 to -2.1)	<0.001	0.830
	Set 5	96.5 ± 22.4	91.9 ± 22.5	-4.7 (-6.4 to -2.9)	<0.001	0.950
RPE (0-10)						
	Set 1	6.4 ± 1.2	6.3 ± 1.2	-0.05 (-0.39 to 0.29)	0.760	0.001
	Set 2	6.9 ± 1.2	6.5 ± 1.6	-0.44 (-0.96 to 0.08)	0.098	0.024
	Set 3	7.2 ± 1.4	7.0 ± 1.2	-0.21 (-0.66 to 0.25)	0.370	0.004
	Set 4	7.7 ± 1.1	7.0 ± 1.3	-0.64 (-0.98 to -0.30)	<0.001	0.540
	Set 5	8.2 ± 1.2	7.0 ± 1.3	-1.1 (-1.6 to -0.69)	<0.001	0.920

%1RM = percentage of 1RM; IVT = individualised velocity target; RPE = rating of perceived exertion

*mean ± SD

Physiological outcomes

Pre-to-post changes in CMJ height (-0.75 cm, 95% CI: -1.6 to 0.10 cm) and blood lactate concentration (-0.50 mmol/L, 95% CI: -1.0 to 0.01 mmol/L) were statistically equivalent between IVT and %1RM sessions (Table 2).

Perceptual outcomes

Average session RPE was significantly lower in the IVT session compared with the %1RM session (-0.49, 95% CI: -0.77 to -0.21). RPE in sets 1-3 were equivalent between sessions, but RPE in sets 4 and 5 were significantly lower during IVT (Table 3). Perceived fatigue 24-hours after the strength training sessions was equivalent between IVT and %1RM (0.11 on a 10-point scale, 95% CI: -0.41 to 0.63). However, perceived muscle soreness was not different nor equivalent following IVT and %1RM sessions (-0.56 on a 10-point scale, 95% CI: -1.1 to 0.03) (Figure 2).

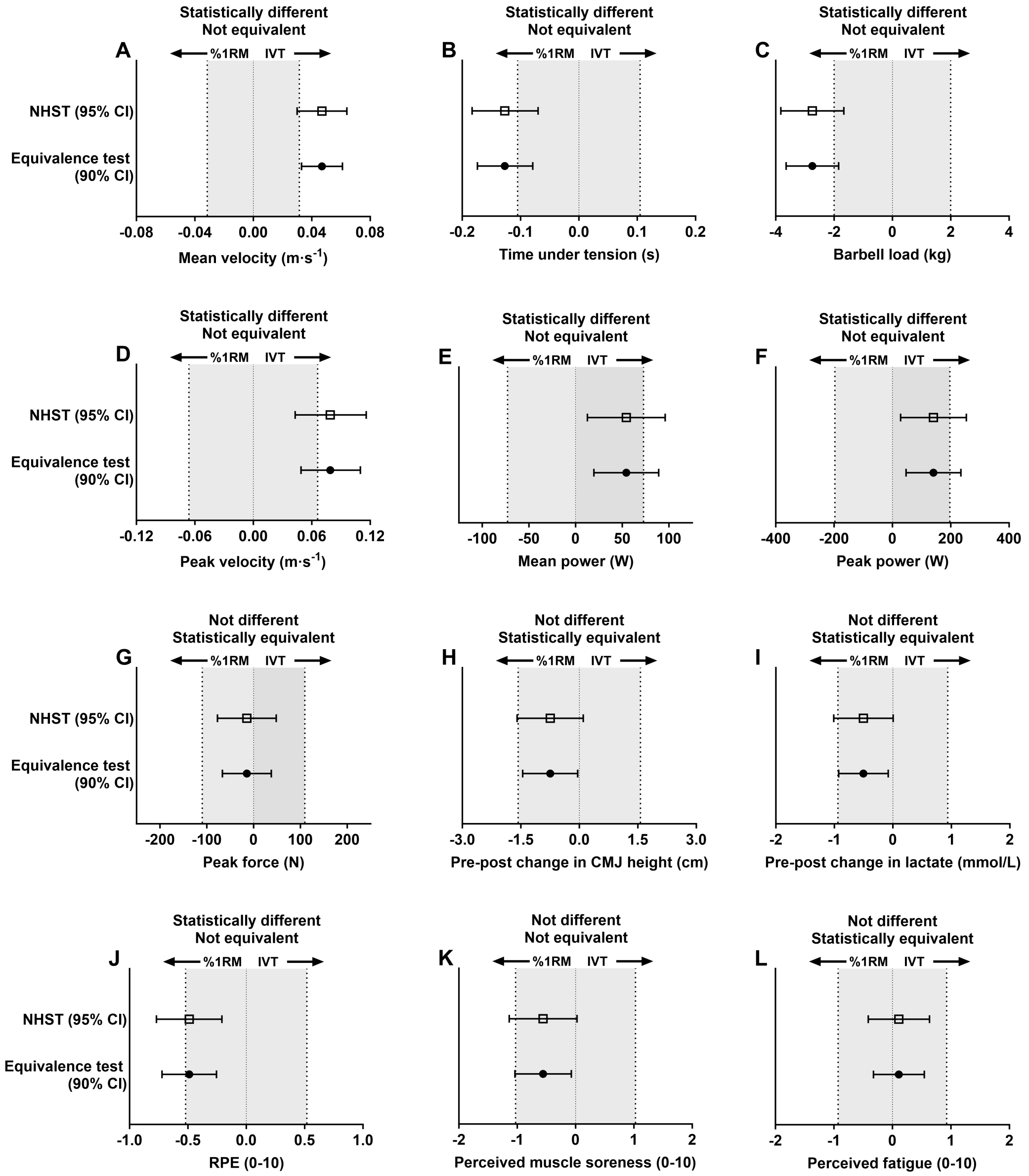

Figure 2: Differences in resistance training responses. Plots display mean differences and confidence intervals with grey shaded area showing equivalence bounds. Panels show (A) mean velocity; (B) time under tension; (C) barbell load; (D) peak velocity; (E); mean power; (F) peak power; (G) peak force; (H) pre-post change in countermovement jump (CMJ) height; (I) pre-post change in blood lactate concentration; (J) rating of perceived exertion (RPE); (K) perceived muscle soreness; and (L) perceived fatigue. Differences calculated as the mean score in the individualised velocity target (IVT) minus the mean score in the percentage of one repetition maximum (%1RM).

Discussion

This is the largest cross-over study to date to compare the effects of IVT and %1RM on acute biomechanical, physiological, and perceptual responses to resistance exercise. IVT increased movement velocity and decreased time under tension in repeated sets of free-weight back squats compared to %1RM. However, metabolic responses and neuromuscular fatigue immediately following exercise cessation, and perceived fatigue 24-hours post-exercise, were equivalent between IVT and %1RM sessions.

Using IVTs increased mean velocity in five sets of the back squat by an average of 0.05 $m \cdot s^{-1}$, which we defined a priori as the minimum important difference. This finding aligns with that from a cross-sectional study with 15 resistance-trained men, which reported mean velocity in the back squat was 0.07 $m \cdot s^{-1}$ higher when training load was adjusted using IVT compared to using a fixed load based on %1RM (Banyard et al., 2019). In our study, the increase in mean velocity was accompanied by enhanced peak velocity, mean power, and peak power, and mirrored changes in barbell load. The greatest difference in mean velocity was observed in the final (fifth) set of back squats, and IVT minimised RPE and the decline in repetition velocity in sets 4 and 5. Collectively, our findings suggest that IVT operates to increase movement velocity and reduce RPE during resistance exercise by reducing barbell load when movement velocity drops below an individually-tailored target threshold.

Performing back squats with greater concentric movement velocity, over time, may promote velocity-specific adaptations, including reduced antagonist coactivation, greater early phase neural drive, and better coordination (Almåsbakk & Hoff, 1996; Balshaw et al., 2016; Pousson et al., 1999). By contrast, evidence of lower barbell load and time under tension in our study suggests that IVT may be suboptimal for muscle hypertrophy based on evidence that higher training volumes lead to greater gains in muscle mass (Pareja-Blanco et al., 2016; Schoenfeld et al., 2019). Thus, IVT modifies the kinematic and kinetic responses to resistance exercise and, whether this is considered adaptive or maladaptive, depends on the training objective and desired adaptation(s). It should be noted, however, that the effect of IVT on training-related adaptations is currently uncertain owing to the very low quality of evidence (Orange et al., 2022).

Our study showed that the pre- to post-exercise changes in blood lactate concentration and CMJ height were equivalent following IVT and %1RM sessions (Figure 2). In other words, differences in these outcomes were too small to be considered important. We found a similar (equivalent) effect for perceived fatigue recorded 24-hours after IVT and %1RM sessions, which aligns with our previous research (Orange, Metcalfe, Robinson, et al., 2020). The effect estimates have excellent precision; for example, the width of the 95% confidence interval for the difference in CMJ height was just 1.7 cm, which is less than the minimum detectable change (Attia et al., 2017). These findings challenge the commonly held belief that modest reductions in barbell load and time under tension will lead to less neuromuscular fatigue and enhanced recovery (Orange et al., 2022).

Interestingly, rating of muscle soreness 24-hours after IVT and %1RM was neither different nor equivalent. This finding suggests more research is needed to elucidate the effect of using IVT on post-exercise muscle soreness, and reinforces the added value of using equivalence tests alongside null-hypothesis significance tests.

This study has many important strengths, including a large sample size of resistance-trained adults, precise estimates, embedded open research practices, and the measurement of a multitude of biomechanical data within and across sets, which may guide hypotheses in future research. Limitations include a lack of participant diversity in terms of age and ethnicity, which could mean our findings are less generalisable to, for example, older and minority ethnic populations. We focused on the free-weight back squat because it is a fundamental exercise used in resistance training interventions and to align with previous research (Banyard et al., 2019; Orange, Metcalfe, Robinson, et al., 2020). However, the application of VBT methods may induce different neuromuscular and metabolic responses to resistance training depending on the exercise used (Jukic et al., 2022; Rodríguez-Rosell et al., 2018). While pre-session CMJ height was statistically equivalent between conditions (equivalence p-value = 0.001), we did not assess CMJ height prior to the 1RM assessment, and therefore we cannot guarantee that participants performed the initial 1RM in the same physical condition. Furthermore, we only assessed CMJ height (as a surrogate for neuromuscular fatigue) at one timepoint immediately post-exercise. Resistance training can induce neuromuscular fatigue for up to 72 hours (Thomas et al., 2018), and thus it is possible that we missed potential differences between conditions at later timepoints.

In conclusion, using individualised velocity targets to regulate resistance training load operates to increase movement velocity, minimise time under tension, and lower RPE in repeated sets of the free-weight back squat by reducing barbell load when movement velocity drops below an individually-tailored threshold. Metabolic responses and neuromuscular fatigue immediately following exercise cessation, and perceived fatigue 24-hours post-exercise, were equivalent between IVT and %1RM sessions. Therefore, using individualised velocity targets may provide a greater stimulus for velocity-specific adaptations than %1RM but does not meaningfully influence post-exercise fatigue.

Additional Information

Data Accessibility

The study protocol was prospectively registered on Open Science Framework (https://osf.io/kdnuy). All data and code are available on the Open Science Framework project page (DOI 10.17605/OSF.IO/R5BGY; https://osf.io/r5bgy)

Author Contributions

- Contributed to conception and design: STO
- Contributed to acquisition of data: CG, CM, LP, KS, SC, LG, CB
- Contributed to analysis and interpretation of data: STO
- Drafted and/or revised the article: STO, CG, CM, LP, KS, SC, LG, CB, WP
- Approved the submitted version for publication: STO, CG, CM, LP, KS, SC, LG, CB, WP

Conflict of Interest

Authors have no conflicts of interest to declare.

Funding

This study did not receive any external sources of funding.

Acknowledgments

We would like to thank Nik Toma and Ben Newell for assisting with data collection.

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