Acute fatigue, and perceptual responses to resistance exercise

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Abstract

Introduction: Despite assumptions, there is an absence of research on acute fatigue responses to high- and low-load and advanced technique resistance exercise.

Methods: Trained males (*n*=8; 27.2 ±7.4years; 180.0 ± 6.6cm; 86.6 ±10.3kg) were assessed for decrement in maximal voluntary isometric torque (MViT) and perceived effort and discomfort following heavier load (HL; 80% MViT), lighter load (LL; 30% MViT), forced repetitions (FR) and breakdown set (BD) training protocols.

Results: Analyses revealed a significant reduction in MViT ($p < 0.05$) with a significant between condition effect, and significant post hoc pairwise comparisons between LL and both HL ($p = 0.044$) and FR ($p = 0.013$). There were no significant between condition effects for effort or discomfort ($p > 0.05$).

Discussion: Fatigue as a decrement in force production appears to follow a more complex relationship than simply 100% minus the force requirements of the task relative to a maximal voluntary contraction.

Key Words: high-load, low-load, muscle damage, isometric strength, fatigue, advanced resistance exercise

Introduction

Resistance training is often performed primarily with the goal of increasing muscular size and/or strength[1]. However, whilst there is a general consensus that maximal recruitment of motor units (MUs) is required to optimise strength and hypertrophy adaptations[2-4] there is a lack of research considering the acute fatigue responses to differing resistance training stimuli. Previous research has hypothesised that reaching momentary failure by exercising at ~30% 1-repetition maximum (RM) would incur ~70% muscle fatigue, or reaching contractile muscular failure exercising at ~70% 1RM would incur ~30% muscle fatigue[5,6]. This seems logical since momentary concentric failure would occur when there is an inability to produce the necessary force to overcome an external load. In essence, fatigue (defined herein as a loss of force/torque production) should be equal to 100% minus the force/torque requirements of the task relative to a maximal voluntary contraction. Though this appears logical, there is currently a lack of research considering the assessment of strength after a fatiguing bout of exercise[7].

Few studies have considered fatigue resulting from resistance exercise at varying loads (i.e. heavier- and lighter-loads), and those which have done so may not reflect the acute decrease in maximal voluntary isometric torque (MViT) incurred or represent ecologically valid resistance training protocols. For example Behm et al.[8] compared MViT of the elbow flexors following 5-, 10-, and 20-repetition maximum (RM). However, a rest time of 30 seconds between exercise set and re-test of MViT would have allowed considerable recovery. A more recent study by Marshall et al.[9] using heavy- (80% MViT) and light-load (40% MViT) knee extension exercise used a complex volume-equated design, which included interpolated twitches and as such, might not represent conventional training routines. Thus there is a current dearth of literature considering the acute fatigue response and practical implications of exercising to momentary failure considering heavier- and lighter-load resistance training strategies. Further, since advanced training methods such as forced repetitions[10] and breakdown set training[11] are commonly used and intended to increase fatigue from resistance training, these should also be investigated.

Another consideration for the acute role of fatigue during resistance training under different loading conditions is its impact upon perceived effort and discomfort. Fisher et al.[12] recently discussed effort (the amount of mental or physical energy being given to a task) and discomfort (the physiological and unpleasant sensations associated with exercise [13]) in the context of heavier- or lighter-load resistance training strategies. They suggested that, although there should be similarities in effort due to the nature of contractions upon reaching momentary failure (i.e. maximal), there might be differences in discomfort due to the increasing number of repetitions and longer time under muscular tension as a result of using low-loads[14,15]. Smirnaul[16] adds that, repetitive *maximal* contractions will induce a greater degree of discomfort than a single maximal contraction, even though effort would be the same (e.g. maximal). In this sense, advanced training techniques such as breakdown sets and forced repetitions might also induce a greater degree of discomfort than traditional exercise sets since participants perform multiple maximal muscle actions. Indeed, effort is thought to originate from the primary motor cortex independently of peripheral afferent feedback[13,17] and thus a differentiation of perceived effort from discomfort should be expected under certain conditions.

With the above in mind the present study considered the acute fatigue (decrease in MViT) responses to heavier- and lighter- load, and advanced method (breakdown set and forced repetition) resistance exercise to momentary failure. Based on existing literature we hypothesised that decrement in force production and reported values for discomfort would increase in relation to decreasing load at exercise cessation.

Materials and Methods

Study Design

A repeated measures randomised crossover design was adopted to examine the acute effects of four different resistance exercise conditions (heavier-load; HL, lighter-load; LL, forced repetitions; FR and breakdown sets; BD) for fatigue response and ratings of effort and discomfort. The study was approved by the Health, Exercise and Sport Science research ethics committee (ethics code: HESS#341) and was conducted within the Sport Science Laboratories at the first author's institution.

Participants

An *a priori* power analysis of effect sizes (ES) for acute decrease in MViT was conducted. As no existing data were available regarding acute fatigue responses to the conditions examined we opted to base our analysis on a moderate between group ES of 0.5 to determine participant numbers (*n*). Participant numbers were calculated using G*Power[18,19]. These calculations showed that a minimum of 7 participants were necessary to meet the required power of 0.8 at an alpha value of $p < 0.05$ for the statistical analyses proposed (see below).

8 trained (e.g. had participated in structured RT for $\geq 2\ d\cdot wk^{-1}$ including intermittent use of advanced training methods such as breakdown training and forced repetitions for >6 months) males were recruited (see results section for participant characteristics). All

participants completed a physical activity readiness questionnaire (PARQ) and informed consent, and were accepted for inclusion if they had no signs or symptoms of disease, no orthopaedic injuries, and were not using any medication or performance enhancing substances which might affect the study.

Testing

All participants completed a familiarisation session during which they performed testing as described below. During the participants' familiarisation session, the machine set-up was assessed and recorded. Prior to any testing, participants performed a standardised warm-up on a cycle ergometer (Monark, Ergomedic 874e), for 5 minutes up to 60% age-predicted maximum heart rate (APMHR). A specific dynamic bilateral warm-up was then completed (80 lbs/~36 Kgs) using a 2second: 1second: 3second (concentric: isometric: eccentric) repetition duration, for 10-15 repetitions on the MedX knee extension dynamometer (MedX, Ocala, FL) used for testing and exercise conditions. Maximal isometric knee extensor torque was then measured bilaterally using the MedX knee extension dynamometer. The MedX knee extension machine has a high test-retest reliability, reported as r = 0.90-0.96[20].

Participants were seated in the knee extension machine and the seat was adjusted to align the lateral epicondyle of the femur with the axis of rotation of the MedX knee extension machine. Each participant's lower limbs were bound to a pad (through which they would later push against) and a hip belt was tightened to avoid unwanted movement at the pelvis when pushing through the knee extensors.

A practice isometric test was then performed at 3 joint angles; near maximal knee flexion (e.g. 108˚), near maximal knee extension (e.g. 12˚) and a mid-point between these two angles. MViT was then measured at 5 pre-determined angles (108˚, 84˚, 60˚, 36˚, 12˚) using the following process. Participants were asked to exhale and build to maximal force for 2-3 seconds, and then relax over a further 2-3 seconds. To assist in obtaining maximal effort, participants were given verbal encouragement throughout maximal testing. This testing method was performed before, and immediately after (< 10 seconds) each of the following exercise conditions. The use of the same machine for the exercise condition and post-exercise testing permitted immediate testing, ensuring almost no rest.

Exercise conditions

All participants completed four conditions performed in a randomised order, at the same time of day with 1 week between conditions. Repetition duration was controlled for all conditions to 2s: 1s: 3s (as per the warm-up) using a metronome to aid pacing (Quartz Metronome SQ SOV, Seiko). Loading for each exercise condition was determined based on the immediately preceding MViT. The training load, described below, was calculated based on the MViT at 84° (the maximal torque of the angles tested). The conditions were:

- Heavier-load (HL); participants performed dynamic repetitions to momentary concentric failure with a load equating to 80% of their MViT.
- Lighter-load (LL); participants performed dynamic repetitions to momentary concentric failure with a load equating to 30% of their MViT.
- Forced repetitions (FR); participants performed dynamic repetitions to momentary concentric failure with a load equating to 80% of their MViT. However, upon reaching momentary failure the research assistant provided sufficient additional force to the participant to complete the concentric phase only. Participants were still required to pause for 1 sec with the load at full knee extension and lower the load at

the required repetition duration. Exercise was terminated when the participant could no longer pause with the load in the isometric phase of the repetition.

- Breakdown sets (BD); participants performed dynamic repetitions to momentary concentric failure with a load equating to 75% of their MViT. However, upon reaching momentary failure the load was immediately reduced to 80% of their initial training load (e.g. 80% of 75% MViT (~60% of their original MViT)) and upon reaching momentary failure a second time the load was immediately further reduced to 60% of their initial training load (e.g. 60% of 75% MViT (~45% of their original MViT))[21].

This study design permitted 3 conditions where decrease in MViT might be hypothesised (HL 80%, LL 30%, BD 45%, resulting in expected decrements in force production of ~20%, ~70% and ~55%, respectively) and one condition which served as an unknown (FR). Immediately following each exercise condition (but prior to post-condition MViT testing), each participant was asked to report a rating of perceived exertion for effort (RPE-E) and discomfort (RPE-D) using 0-10 scales that permitted appropriate differentiation of the two perceptions[22,23].

Statistical Analysis

Strength was considered as peak MViT which occurred at 84˚ for all participants. Fatigue was considered as the decrease in MViT to the training condition (post strength – pre strength). The independent variable considered was the exercise condition (HL, LL, FR and BD) and the dependent variables included pre- strength (the MViT prior to each condition), the absolute change in strength (pre MViT – post MViT), RPE-E and RPE-D. An intra-class correlation coefficient (ICC) was conducted to assess pre-test MViT test-retest reliability at 84˚ between conditions. A Shapiro-Wilk test was conducted to examine whether data met assumptions of normality of distribution and Mauchly's test was used to examine assumptions of sphericity for repeated measures. Where assumptions of normality and sphericity were met, repeated measures analysis of variance (ANOVA) was used to compare within participants across the conditions. Where a significant effect by condition was found, post hoc pairwise comparisons with a Bonferonni procedure were conducted to examine differences between conditions. For variables which did not meet assumptions of normality of distribution, a Friedman test was used to compare within participants across the conditions. Where a significant effect by condition was found, Wilcoxon signed ranks tests were conducted to examine differences between conditions.

All statistical analyses were performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Portsmouth, Hampshire, UK) and $p<0.05$ set as the limit for statistical significance. Further, 95% confidence intervals (CI) were calculated to examine within-condition significance in addition to ES using Cohen's *d*[24] for absolute change in strength for each condition, and differences between conditions for average RPE-E and RPE-D, where an ES of 0.20-0.49 was considered as small, 0.50-0.79 as moderate and ≥0.80 as large.

<u>Results</u>

Participant characteristics were (mean ± SD); age = 27.2 ±7.4 years, height = 180.0 ±6.6 cm, body mass = 86.6 ±10.3 kg, and body mass index = 26.7 ±2.3 $kg \cdot m^2$.

Repeated measures ANOVA revealed no significant effect by condition for pre-strength (MViT; HL = 564.44 ±75.27Nm, LL = 553.42 ±80.64Nm, FR = 558.67 ±83.76Nm, BD = 553.09 ±119.06Nm; $F_{(3, 21)} = 0.840$, $p = 0.487$). The ICC for pre- MViT showed very high reliability; ICC = 0.926 (95% CI, 0.779-0.984) supporting the use of MViT for fatigue response testing in our laboratory.

There was a significant effect by condition for absolute change in strength (HL = -75.77 ±61.40Nm, LL = -206.97 ±78.06Nm, FR = -74.24 ±46.52Nm, BD = -145.95 ±118.24Nm; $F_{(3, 21)} = 5.842$, $p = 0.005$). Pairwise comparisons for between condition differences were as follows: HL compared to LL ($p = 0.044$), HL compared to FR ($p > 0.999$), HL compared to BD ($p = 0.687$), LL compared FR ($p = 0.013$), LL compared to BD ($p > 0.999$), and FR compared to BD ($p = 0.632$). ESs for absolute change in strength were large for all conditions (HL = -1.23, LL = -2.65, FR = -1.60, and BD = -1.23) and 95%CIs suggested all conditions produced significant absolute changes in strength. Further, mean relative change in strength for each condition did not meet our hypothesised values, however, there was considerable interindividual variability in the decrement in force production for each condition (HL = -13.48% [+0.80% to -36.89%], LL = -37.94% [-20.11% to -61.18%], FR = -13.20% [+1.36% to -25.70%], and BD = -25.64% [-1.50% to -62.02%]). Figure 1 shows mean decrement in MViT for each condition in addition to individual responses.

RPE-E and RPE-D did not meet assumptions of normality. Friedman test revealed no significant effect by condition for either RPE-E ($\chi^2 = 0.350$, $p = 0.950$) or RPE-D ($\chi^2 = 7.762$, $p = 0.051$). RPE-E and RPE-D for each condition is presented in table 1.

Discussion

Acute Fatigue

Previous articles have suggested that fatigue as a decrement in force/torque production should be equal to 100% minus the force/torque requirements of the task relative to a maximal voluntary contraction[5,6]. However, our data does not support this. Analysis confirmed a significant reduction in MViT following each condition; however, though there were descriptive and ES differences across conditions, there were only significant differences between LL and both HL and FR. Examination of the 95%CIs for each condition suggests a high likelihood that the true population mean for fatigue in the LL condition is greater than for the HL condition. Furthermore, the decrease in MViT was not as expected based on loading schemes. The data presented shows a trend towards a greater % decrease in MViT as the preceding training load becomes progressively lighter when training to momentary failure. There was also considerable interindividuality in the decrease in MViT response to each condition (see Figure 1). From this it seems likely that: 1) recovery of force/torque production after its loss may occur more rapidly than our assessment was able to detect (e.g. within the 10 second interval between exercise and post-testing) and is possibly a reflection of the heterogeneous muscle fibre phenotypes seen in humans[25]; and 2) there may be a critical threshold to fatiguing exercise which occurs on an interindividual basis[26].

The present data supports previous studies that generally show a greater reduction in maximal torque for low- compared to high-load conditions[9]. However, our results suggest there is a large heterogeneity of fatigue within the present sample and/or fatigability of differing muscle fibre types between participants. Previous research suggested a linear correlation between fatigability and % fast twitch fibres (r = 0.86; 39), although, more recently in a review article, Enoka[27] has suggested that whilst there is a range of fatigability within MUs across the population, distinction between MUs based on fatigability should be avoided. We should also acknowledge the multifarious physiological processes and the multi-faceted nature in which fatigue reduces force below the required threshold. Previous research has suggested upregulation in central motor output for low loads, ultimately similar to high-load training[9]. When combined with the larger volume (number of repetitions), volume-load (repetitions x load) as well as longer time under tension inherent in low-load exercise to momentary failure this elevated central motor output appears to produce higher levels of fatigue and ultimately greater reductions in maximal torque. However, due to task specificity this might only apply to traditional (e.g. concentric and eccentric) isolated muscle actions for the knee extensors as presented herein.

Force maintenance with fatiguing contractions is a complex relationship resulting in both facilitating and inhibiting mechanisms[28,29]. Some muscular stimulation >80% 1RM can enhance performance (e.g. through post-activation potentiation[30]). However, during repeated or sustained muscular contractions, fatigue develops progressively until the required force can no longer be produced. Further, fatigue can be considered as occurring centrally *("a decrease in the number and discharge rates of the MUs"*) or peripherally *("a decrease in the contractile strength of the muscle fibres and changes in the mechanisms underlying the transmission of muscle action potentials")*[29,31]. Since mechanistic processes were not assessed, we can only speculate as to any possible mechanisms which might result in differing decrease in MViT as a result of the different exercise conditions.

Effort and Discomfort

Authors have hypothesised that training to momentary failure with a lighter- compared to heavier-load might incur a greater degree of discomfort[12,17]. However, our analyses failed to identify any significant differences for effort (RPE-E) and discomfort (RPE-D) between HL, LL, BD and FR conditions. This is contradictory to previous research where participants reported higher values for discomfort for LL compared to HL throughout a training intervention[23].The present data might be a result of the single set methodology applied where multiple sets for each condition might amplify effects of effort and discomfort (as in the intervention study[23]). Also, as stated, we should consider the possibility of a type II error between conditions (HL, LL, BD and FR) for effort and discomfort. Our *a priori* power analysis was conducted for acute decrease in MViT, as such our study might not have met power for the measures of effort and discomfort. Our analysis revealed $p = 0.051$, which might have reduced to statistical significance with a marginally greater sample of participants/fewer conditions. Further, both the LL and BD conditions produced RPE-D ratings that exceeded the standard error of measurement for this scale[22] and so though the statistical comparisons were likely underpowered these could be considered meaningful differences. However, again there was considerable interindividual variation in perceived discomfort between the conditions (HL = 6 to 10, LL = 8 to 10, FR = 6 to 10, BD = 6 to 10).

Current research supports similar strength and hypertrophy adaptations from both high- and low-load resistance training interventions[4,6,23,32]. However, we have presented significantly greater decrement in MViT immediately following exercising at LL compared to HL and FR conditions. Furthermore, we report descriptively greater degrees of discomfort when exercising with very low loads (e.g. 30% MViT) which is supported by previous research[23]. These results might suggest caution toward the use of very low loads (e.g. 30% MViT) because of the potentially weakening acute responses. Furthermore, participants might be more encouraged to consider the use of heavier-load resistance exercise (e.g. 80% MViT) if there is a lower degree of discomfort, or if the likelihood of reaching momentary failure is improved as a result of a lesser discomfort whilst exercising to the same degree of effort[12,23]. However, we should consider that decrement in force production and discomfort might change across time following the exercise interventions. The present study only considered the immediate response, whereas future research should consider the change in MViT and possibly delayed resulting muscle damage, as well as discomfort, over the subsequent 24-48 hours. This would also permit volume or volume-load matched conditions to be considered.

Finally, we should recognise the limitation that the present study did not include female participants and, as such, the data cannot be generalised across the population. Future research might consider comparison between males and females as well as investigating different muscle groups (e.g. the lumbar extensors) and different exercise types (e.g. multi-joint).

Conclusions

Our data suggest a greater decrease in MViT as a result of lighter final load at momentary failure. Furthermore, we should consider that when LL, compared to HL, resistance exercise is performed there is potential for a higher degree of discomfort with LL exercise. With this in mind, and since chronic strength and hypertrophy responses might be similar when using HL and LL, this might encourage persons to self-select heavier loads for resistance training to avoid unnecessary fatigue and discomfort. Alternately persons might use extended rest intervals between sets and exercises or choose a reduced volume if using a final lighter load (e.g. as a result of breakdown sets), and thus avoid incurring greater acute fatigue.

List of acronyms/abbreviations

Age-predicted maximum heart rate	APMHR
Analysis of variance	ANOVA
Breakdown set	BD
Confidence intervals	CI

Effect size	ES
Electromyography	EMG
Forced repetitions	FR
Heavier load	HL
Intra-class correlation coefficient	ICC
Lighter load	LL
Maximal voluntary isometric torque	MViT
Motor unit	MU
Newton metre	Nm
Physical activity readiness questionnaire	PARQ
Rating of perceived exertion for discomfort	RPE-D
Rating of perceived exertion for effort	RPE-E
Repetition maximum	RM
Standard deviation	SD

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Table 1. Mean (±SD) for effort and discomfort in each condition

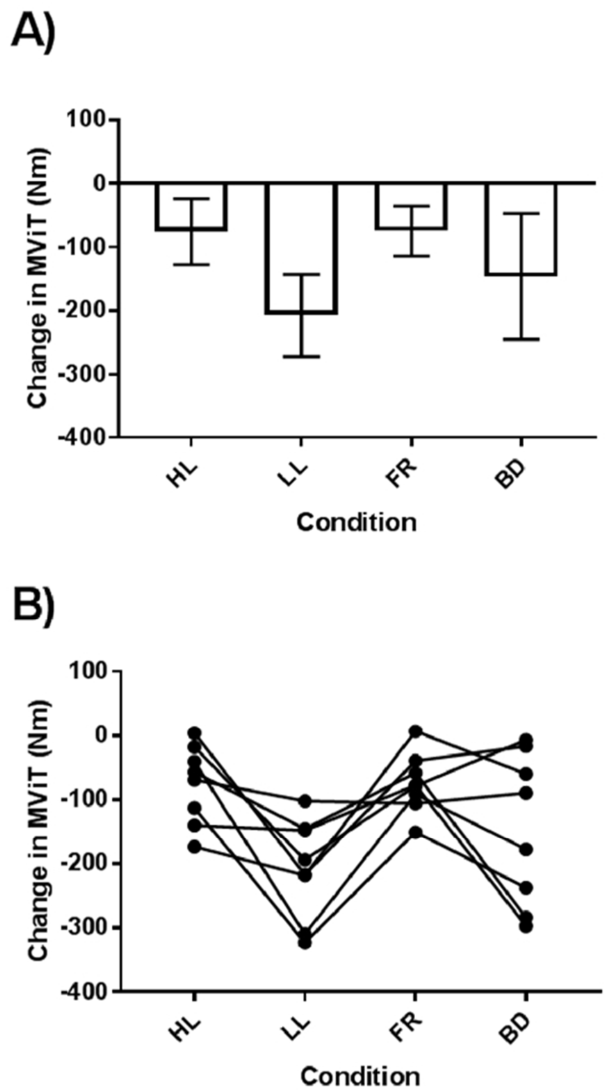
Condition	RPE-E	RPE-D
High Load	8.75 ±1.39	7.75 ±1.39
Low Load	8.875 ±0.99	9.00 ±0.93
Forced Repetitions	9.00 ±1.20	7.50 ±1.93
Breakdown	9.00 ±1.39	8.88 ±1.36

RPE-E = Rating of Perceived exertion for effort

RPE-D = Rating of Perceived exertion for discomfort

Figure Legends

Figure 1. A) Mean decrement in maximal voluntary isometric torque (MVIT) for each condition with 95%CIs, and B) individual responses in MViT decrement for each condition. (HL=heavier load, LL=lighter load, FR=forced reps, BD=breakdown sets, FR=forced reps)



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