AN EVALUATION OF SUPRAMAXIMALLY LOADED ECCENTRIC LEG PRESS EXERCISE

MELISSA HARDEN,1,2 ALEX WOLF,2 MARK RUSSELL,3 KIRSTY M. HICKS,1 DUNCAN FRENCH,4 AND GLYN HOWATSON1,5

1Department of Sport Exercise and Rehabilitation, Faculty of Health and Life Sciences, Northumbria University, Newcastle upon Tyne, United Kingdom; 2English Institute of Sport, Manchester, United Kingdom; 3Department of Sport, Health and Nutrition, School of Social and Health Sciences, Leeds Trinity University, Leeds, United Kingdom; 4UFC Performance Institute, Las Vegas, USA; and 5Water Research Group, School of Environmental Sciences and Development, Northwest University, Potchefstroom, South Africa

ABSTRACT

Harden, M., Wolf, A., Russell, M., Hicks, K.M., French, D., and Howatson, G. An evaluation of supramaximally loaded eccentric leg press exercise. J Strength Cond Res 32(10): 2708–2714, 2018—High-intensity eccentric exercise is a potent stimulus for neuromuscular adaptation. A greater understanding of the mechanical stimuli afforded by this exercise will aid the prescription of future eccentric training regimens. This study sought to investigate the mechanical characteristics of supramaximally loaded eccentric exercise when using a custom-built leg press machine. Using a within-subject, repeated-measures design, 15 strength trained subjects (age, 31 ± 7 years; height, 180.0 ± 6.8 cm; body mass, 81.5 ± 13.9 kg) were assessed under 3 different conditions: low (LO), moderate (MOD), and high (HI) intensity, which were equivalent in intensity to 110, 130, and 150%, respectively, of peak force during an isometric maximal voluntary contraction (IMVC) performed on leg press at 90° knee flexion. All loading conditions demonstrated a similar pattern of mechanical profile; however, the variables underpinning each profile showed significant (p < 0.01) load-dependent response (LO vs. MOD, MOD vs. HI, LO vs. HI) for all variables, except for average acceleration. Average force associated with each loading conditions exceeded IMVC but equated to a lower intensity than what was prescribed. Repetitions under higher relative load intensity stimulated greater average force output, faster descent velocity, greater magnitude of acceleration, shorter time under tension, and a decline in force output at the end range of motion. This research provides new data regarding the fundamental mechanical characteristics underpinning supramaximally loaded eccentric leg press exercise. The information gathered in the study provides a foundation for practitioners to consider when devising loading strategies and implementing or evaluating supramaximally loaded eccentric exercise when using a similar exercise and device.

KEY WORDS force output, load prescription, muscle lengthening

INTRODUCTION

Eccentric resistance exercise classically involves resisting an external load during the descending phase of an exercise movement. When performing eccentric resistance exercise using supramaximal external load (>1 repetition maximum [1RM] or isometric peak force), the active muscle will lengthen while under high tension. Using this loading regimen means that the force imposed by the load exceeds the opposing force offered by the muscle. In these circumstances, muscle force output is in excess of what can be achieved during maximal isometric (19) or concentric (6) exercise, thus can be a means to augment greater muscle tension. Consequently, high-intensity eccentric exercise has been shown on numerous occasions to provide a more potent stimulus for neuromuscular adaptation than concentric training (8,11,14).

There is a wealth of evidence to suggest that following habitual use of high-intensity eccentric exercise, there is an increase in muscle cross-sectional area and morphological alterations of muscle architecture (2), preferential recruitment of type II muscle fibers (13), increase in isometric and concentric force (3,9,10), enhanced task-specific gains in eccentric strength (10), reduced neural inhibition, and increase in muscle activation (1,17). Because these adaptations are precursors to stronger, larger, faster muscle with the potential to generate more power, there is a great deal of interest in this mode of training from athletes, coaches, and practitioners. Especially, those who operate within strength-power–based sports where maximal strength and muscle mass can be important determinants of performance. Unfortunately, the application of high-intensity eccentric training in a performance environment is fraught with problems; administering a sufficient
stimulus in an efficient manner while considering the safety of athletes under extreme loads requires close supervision, assistance, or specialist equipment or all. These limitations have led to a paucity of information in applied settings (compared with more traditional resistance training methods), thereby limiting the evidence about this activity, and importantly, the potential to understand the application for training prescription and adaptation.

To conduct applied investigations of supramaximal eccentric training, coaches and research practitioners must have a safe, achievable, and effective protocol. To ensure this, they must first gain an appreciation of the unique mechanical stimulus that will be exerted on the musculoskeletal system and understand how it may alter with changing conditions. To our knowledge, no study has investigated the mechanical stimulus of supramaximal intensity eccentric exercise using a method that can be replicated in an applied training environment. Therefore, the aim of this research was to investigate 3 supramaximal intensity eccentric leg press exercise conditions, using a bespoke inclined leg press device. Modification and instrumentation of the inclined leg press device removed the potential limitations associated with high-intensity eccentric training practice, such that it was possible to apply very high loads eccentrically and allow an investigation of the fundamental mechanics associated with this mode of exercise. This first step will provide the foundation information that will increase the understanding of the eccentric phase of the leg press exercise and characterize the stimulus afforded by the addition of a supramaximal load. This information will provide practitioners an understanding of the training stimulus provided on similar devices when prescribing, implementing, or evaluating high-intensity eccentric exercise in their research and practice.

**METHODS**

**Experimental Approach to the Problem**

This study used a within-subject, repeated-measures design to investigate the mechanical profile of 3 different supramaximally loaded eccentric exercise conditions: low (LO), moderate (MOD), and high (HI) intensity. Eccentric exercise was performed on an instrumented, custom-built, leg press machine that defaults as a traditional leg press device, but modifications allow it to be converted to an isometric or eccentric device. Using the machines isometric function, load prescription for each condition was calculated from peak force during isometric maximal voluntary contraction (IMVC) performed on leg press at 90° knee angle. A 90° knee angle was chosen for IMVC because it reflected the portion of the leg press movement where force output is most restricted. Also, IMVC was chosen as a prescription method because it was considered time and somewhat energy efficient vs. IRM testing and has previously been shown to have a strong correlation with IRM (12). The magnitude of external load applied to LO, MOD, and HI conditions were equivalent in intensity to 110, 130, and 150% IMVC, respectively. The range of intensities were chosen to ensure that manipulation in external load (independent variable [IV]) was sufficiently different enough to produce mechanical differences in the kinetic and kinematic parameters (dependent variable [DV]). A smaller intensity range may have produced similar data across conditions, thus making it difficult to draw meaningful conclusions for coaching and research practice. All subjects attended 4 testing sessions across 4 consecutive weeks; 1 session per week, on the same day and at the same time each week to avoid the influence of diurnal fluctuations. Session 1 included IMVC familiarization, and following a 10-minute rest interval, IMVC assessment to attain a baseline for eccentric load prescription. This was followed by eccentric exercise familiarization. Sessions 2, 3, and 4 included the assessment of eccentric repetition characteristics under each loading condition, LO, MOD, and HI, in a randomized, counterbalanced order.

**Subjects**

Fifteen male subjects (mean ± SD; age, 31 ± 7 years, height, 180.0 ± 6.8 cm, and mass, 81.5 ± 13.9 kg, respectively) volunteered to participate. All subjects were from a strength-power sport background (e.g., Olympic weightlifting, rugby, athletics, and track sprint cycling), with 11 ± 7 years of resistance training experience, which had included phases of maximum strength training. All subjects were free from musculoskeletal injury for at least 12 months before the study started and reported no musculoskeletal or cardiovascular disorders. The volunteers were required to avoid unaccustomed exercise during the whole study period, refrain from strenuous exercise in the 48 hours before attending each testing, and were instructed to attend each session in a well-hydrated and fed state, having abstained from alcohol in the preceding 24 hours. They were advised to keep a consistent routine (nutrition, hydration, general exercise, and sleep) in the days before attending each testing session, which were completed during the Winter season. Subjects were informed of the benefits and risks associated with the investigation and all study procedures before signing informed consent documentation. The study procedures and consent documentation was approved by Northumbria University Ethics Committee in accordance with The Declaration of Helsinki.

**Procedures**

**Equipment and Instrumentation.** The custom-built 45° incline leg press machine (Sportesse, Somerset, United Kingdom) facilitates performance and assessment of concentric, isometric, and eccentric exercise (Figure 1). The machine’s default is to act as a traditional leg press device, but modifications allow it to be converted to an isometric or eccentric device. The eccentric function of the leg press operated via a pneumatic system enables higher loads (up to 420 kg) to be applied during the eccentric phase of the leg pressing movement. Automatic “unloading” at the predetermined end position (descending part of the lift) allowed the user to return the carriage to the start position. The “unload” was achieved.
Mechanical Characteristics of Eccentric Exercise

with adjustable magnetically operated switches (reed switches) situated on the machine's framework. These switches trigger the application and withdrawal of the imposed resistance when the foot carriage passed each switch, thereby reducing the load to allow the user to return the carriage back to the start position under concentric conditions unassisted. The isometric function of the leg press operates via an inbuilt locking mechanism that can secure the carriage at any position along the machine's framework. The reliability of the machine to administer eccentric force across 15 different loads between 130 and 420 kg on 2 separate occasions were not significantly different (ρ = 0.11) and showed strong reliability (intraclass correlation coefficient [ICC] = 1.00 [95% confidence interval [CI], 1.00–1.00]; coefficients of variation [CV] = 1.2% [95% CI, 0.9–2.0]).

The leg press foot carriage comprises 2, smaller, independent carriages that connect with a removable steel bar. Mounted onto each carriage were separate force plates. Each force plate consists of 2 parallel steel plates with 4, s-type load cells (300 kg limit per cell), which were mounted between each plate in each corner. The 4 load cells fed into a combinator to create a single voltage output. Associated with each force plate was a potentiometer (Hybritron, 3541H-1-102-L; Bourns Ltd., Bedford, UK). The load cells and potentiometers sampled at 200 Hz. The voltage from the load cells and potentiometers were relayed into data acquisition software (LabVIEW 6.1 with NI-DAQ 6.9.2; National Instruments Corporation, Berkshire, UK) on a desktop personal computer. Force-time trace for each force plate (left and right) and displacement- and velocity-time trace for each potentiometer (left and right) were displayed. Raw data were exported from the data acquisition software into Microsoft Excel format (Microsoft Excel 2010, Microsoft Corporation, Washington, USA) and were analyzed offline.

Warm-up. Before testing, a standardized warm-up was completed using a cycle ergometer (Wattbike Pro; Wattbike, Ltd., Nottingham, United Kingdom) pedaling at 70–80 revolutions per minute between 110 and 120 W for 5 minutes. Immediately following this, 5 minutes of dynamic mobility exercises were completed that targeted the trunk, hips, and lower limbs. This was followed by 8, 6, and 4 repetitions of the leg press at an external intensity equivalent to 70, 85, and 100% of body mass, respectively. Each set was separated by 2 minutes.

IMVC Familiarization and Testing. After the warm-up, subjects were familiarized with the IMVC test protocol. Securing the leg press carriage at 90° of the subjects’ knee flexion (verified by goniometry), they completed 3 × 1 repetition at each of the following perceived intensities: 50, 75, and 100% for 3 seconds per repetition. Between each repetition, subjects were given 30 seconds of recovery and 2 minutes of recovery between each intensity. After this, subjects rested for 10 minutes before formally assessing IMVC. This assessment consisted of 3 maximum efforts of 5 seconds, interspersed by 3-minute rest. Subjects were advised to “gradually build up force to reach maximal capacity, until instructed to stop.” Instructions were standardized, and all subjects received the same verbal encouragement during each effort. Data of IMVC were collected using the machine’s force plate system. The trial showing highest peak force was taken for analysis and used for eccentric load prescription. Pilot tests showed that 2 repeated sessions separated by 7 days were not significantly different (ρ = 0.48) and showed strong reliability (ICC = 0.99 [95% CI, 0.95–1.00]; CV = 4.65% [95% CI, 3.15–6.14]).

Eccentric Familiarization and Testing. Familiarization during session 1 included 3 × 3 repetitions with an external load equivalent to 75 and 85% IMVC and 3 × 1 repetitions with an external load equivalent to 100% IMVC, respectively. Preceding the LO trial, an additional 1 repetition with an external load equivalent to 100% IMVC was completed; preceding the MOD trial, an additional 1 repetition with an external load equivalent to 110% IMVC was completed, and preceding the HI trial, an additional 1 repetition with an external load equivalent to 130% IMVC was completed. All repetitions were 3-second eccentric time under tension (TUT). In each session, testing comprised 4 × 1 repetitions at LO, MOD, or HI intensity, separated by 5 minutes to minimize the effects of fatigue. Each session was randomly assigned to LO, MOD, or HI intensity. The same verbal encouragement was provided throughout each testing session.

The performance requirements of the eccentric exercise were to (a) halt the supplementary load before initiating any lowering action; (b) initiate the lowering action as slowly and as controlled as possible and continue this action over the whole range of motion (ROM); (c) resist the carriage from accelerating downward throughout the whole ROM; and (d) react as fast as possible because the eccentric load is withdrawn to push the carriage upward. This last instruction was to promote continued force production throughout the whole ROM and to prevent the subjects from dropping the carriage to the safety stops. During this movement, the following variables were of interest; average force (N), end force (N), TUT (s), average velocity (m·s⁻²), and average acceleration (m·s⁻³). These data were captured between the start of the repetition (maximum displacement of the foot carriage = 10° knee flexion) and the end of the repetition (zero displacement of the foot carriage = 90° knee flexion). These were the locations that corresponded with the application and removal of the added eccentric load. For each condition, the
trial that most satisfied the performance requirements were taken for analysis. Force data for the left and right sides were summed to reflect the bilateral nature of the exercise.

**Statistical Analyses**

Intraclass correlation coefficients and CV (%) including 95% CIs were calculated to determine the repeatability of eccentric performances between 2 repetitions (7). Using SPSS (version 24.0; SPSS, Inc., Chicago, IL, USA), a repeated-measures analysis of variance was used to determine significant differences in the DVs; force (average and end), TUT, velocity, and acceleration between each loading condition (IV) and, where appropriate, a Bonferroni post hoc test. Group data are presented as mean ± SD with 95% CIs. Data are supported with effect sizes (partial eta²); α was set at p ≤ 0.05, a priori.

![Image](image1.png)

**Figure 1.** The leg press device. Left photograph: Incline leg press with unilateral force plates (A), air compression unit (B), removable steel bar insert (C), safety pins (D), and adjustable seat (E). Right photograph: Underneath the foot carriage, adjustable ROM sensors (F).

![Image](image2.png)

**Figure 2.** A representative mechanical profile for a single eccentric leg press repetition under 3 supramaximal loading conditions. Black solid line: low (LO)-intensity loading condition; dark grey solid line: moderate (MOD)-intensity loading condition; light grey solid line: high (HI)-intensity loading condition; dashed black line: peak force during isometric voluntary contraction (IMVC) at 90° knee flexion. A) Force-time profile, B) Displacement-time profile, C) Velocity-time profile, D) Acceleration-time profile.
Mechanical characteristics of eccentric leg press repetitions during LO, MOD, and HI intensity loading conditions.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>LO</th>
<th>MOD</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prescribed force (N)</td>
<td>3,073.8 ± 76.2</td>
<td>3,263.1 ± 124.3</td>
<td>3,857.5 ± 243.1</td>
</tr>
<tr>
<td>Average force (N)</td>
<td>2,812.6 ± 62.2</td>
<td>3,048.2 ± 132.1</td>
<td>3,151.2 ± 248.3</td>
</tr>
<tr>
<td>End force (N)</td>
<td>2,795.4 ± 60.2</td>
<td>3,048.2 ± 132.1</td>
<td>3,151.2 ± 248.3</td>
</tr>
<tr>
<td>TUT (s)</td>
<td>8.1 ± 0.2</td>
<td>4.4 ± 0.2</td>
<td>4.4 ± 0.2</td>
</tr>
<tr>
<td>Average velocity (m s⁻¹)</td>
<td>5.9 ± 0.5</td>
<td>5.9 ± 0.5</td>
<td>5.9 ± 0.5</td>
</tr>
<tr>
<td>Average acceleration (m s²)</td>
<td>16.0 ± 2.2</td>
<td>16.0 ± 2.2</td>
<td>16.0 ± 2.2</td>
</tr>
</tbody>
</table>

*ANOVA = analysis of variance; HI = high-intensity; MOD = moderate-intensity; LO = low-intensity; TUT = time under tension.

**significant difference from LO intensity at alpha level p < 0.05, calculated using Bonferroni post hoc analysis.

- Significant difference from MOD intensity at alpha level p < 0.01, calculated using Bonferroni post hoc analysis.

**significant difference from HI intensity at alpha level p < 0.01, calculated using Bonferroni post hoc analysis.

**significant difference from LO intensity at alpha level p < 0.01, calculated using Bonferroni post hoc analysis.

- Significant difference from MOD intensity at alpha level p < 0.01, calculated using Bonferroni post hoc analysis.

- Significant difference from HI intensity at alpha level p < 0.01, calculated using Bonferroni post hoc analysis.

RESULTS

The ICCs revealed a high within-session reliability for average force: LO (ρ = 0.17; ICC = 1.00 [95% CI, 1.00–1.00]; CV = 0.92% [95% CI, 0.63–1.22]), MOD (ρ = 0.41; ICC = 1.00 [95% CI, 1.00–1.00]; CV = 0.83% [95% CI, 0.56–1.1]), and HI (ρ = 0.98; ICC = 1.00 [95% CI, 1.00–1.00]; CV = 0.52% [95% CI, 0.35–0.68]). Reliability for TUT was acceptable: LO (ρ = 0.69; ICC = 0.96 [95% CI, 0.90–0.99]; CV = 7.54% [95% CI, 5.12–9.96]), MOD (ρ = 0.53; ICC = 0.95 [95% CI, 0.86–0.98]; CV = 8.61% [95% CI, 5.85–11.38]), and HI (ρ = 0.65; ICC = 0.98 [95% CI, 0.94–0.99]; CV = 5.99% [95% CI, 4.06–7.91]). The results show that IMVC peak force equated to 2,794.4 ± 811.9 N (95% CI: 2,325.7–3,263.1). Average force associated with each loading conditions exceeded IMVC peak force but was less than the prescribed external force. This meant that the actual intensity of each loading condition was equivalent in intensity to 101.0 ± 4.0% (95% CI, 98.3–102.8), 116.0 ± 4.0% (95% CI, 113.8–118.2), and 132.3 ± 8.1% (95% CI, 127.8–136.7) for LO, MOD, and HI, respectively. All loading conditions demonstrated a similar pattern of mechanical profile (Figure 2); however, the variables underpinning each profile showed significant (ρ < 0.01) load-dependent response (LO vs. MOD, MOD vs. HI, LO vs. HI) for all variables, except for average acceleration, which was significantly different between LO and HI only (ρ = 0.05) (Table 1). Force at the end ROM was 1, 3, and 5% less than the average force measured over the ROM for LO, MOD, and HI trials, respectively.

DISCUSSION

The aim of this research was to investigate the fundamental mechanical characteristics associated with supramaximal intensity eccentric leg press exercise. The results showed that the heavier relative external load stimulated greater average force output which, in turn, was associated with a faster descent velocity and shorter TUT. With each increment in external load (LO vs. MOD, MOD vs. HI), average force output increased approximately 12% and average descent velocity increased by approximately 35%, which was equivalent to a decrease in TUT of approximately 26%. The eccentric force output under each loading condition was less than the force imposed by the external load. Because of this, the intensity of the supramaximal load was less than the prescribed 110, 130, and 150% relative to peak force exerted during the IMVC. Each condition displayed a similar mechanical profile throughout the ROM; but with the heavier external load, a decrease in force output and concomitant increase in velocity and acceleration was prominent toward the end ROM (Figure 2).

In this study, supramaximal eccentric-only exercise was used to explore the strength potential of eccentric actions without the limitation of concentric force capacity. The eccentric protocol was focused on reducing net forces to
decelerate the foot carriage and descend in a slow and controlled movement. This eccentric-only movement has minimal involvement of the stretch-shortening cycle (5), and the slow nature of this exercise perhaps lacks task specificity to some sports (18). However, the extended TUT at high levels of force exceeds what can be achieved with traditional resistance exercise. Consequently, this could provide a potentially powerful stimulus for musculoskeletal adaptation and thereby be of use for long-term athlete development to increase muscle strength and size, given that the mechanical stimuli is integral to induce adaptation (10). To understand the acute and chronic responses to this type of eccentric exercise and the different force-TUT interactions, more research is warranted, particularly given the growing interest in elite sport to maximize adaptation from eccentric loading.

The force-time traces showed that the eccentric protocol induced a relatively stable force output across the majority of the working range (Figure 2A). Because of this feature, average force was used to quantify the relative intensity of each eccentric effort. On this basis, the intensity of each loading condition equated to approximately 101, approximately 116, and approximately 132% of peak force exerted during IMVC. The disparity in prescribed vs. actual load is attributed to the voluntary reduction in force output to assist the carriage to descend. In all conditions, force of the external load and muscle force are not equal; the slower the intended velocity of the descent, the closer the force expressed by the subject to equaling the force imposed by the load (16). Therefore, in the absence of instrumentation, when training with slower velocities, the external load would provide a good representation of the intensity of the force being exerted. The opposite is true for repetitions with faster descent velocity, whereby faster velocities will be more distant from the prescribed load.

Under these intensities, the higher loading conditions tended to show a force decline toward the end ROM (Figure 2A). This indicates that the force of the applied external load became too great to resist at the same target velocity. This resulted in some acceleration toward the end of the ROM. It is important to be mindful of these changes in acceleration at higher intensities if the intention of the training stimulus is to provide an even and stable stimulus throughout the working range. Previously, practitioners and researchers have used a 3% decline in force as a cutoff criterion to ensure the provision of a stable stimulus (15). When applying this criterion to these data, the LO trial showed a decline in force output of 1%, MOD declined by 3%, and HI declined by 5%. Based on the above criterion, the efforts under the HI loading condition might not be acceptable. Nonetheless, the force output in the HI condition generated a great deal of muscle tension, so if the aim is to load an athlete with similar loads, practitioners should be mindful that the load is not well tolerated in more flexed positions and could have implications for safe execution of the movement.

The prescription of eccentric load intensity for each condition used angle-specific isometric assessment. Individuals tended to show slightly different responses to the same relative load when prescribing relative to isometric strength. This could be expected given that neural control strategies during eccentric and isometric actions are different (4). As such, it seems apt to suggest that future research should establish task-specific methods of eccentric assessment. This would enable practitioners to accurately determine an individual’s eccentric force-producing capacity and prescribe eccentric training more accurately. Notwithstanding, using the isometric method as a basis for load prescription enabled successful implementation of 3, different, supramaximal eccentric exercise protocols.

The custom-built instrumented leg press reduced common methodological issues regarding the ability to perform high-intensity eccentric exercise efficiently and safely. The outcomes have facilitated the evaluation of the fundamental mechanical characteristics underpinning eccentric exercise during the leg press movement and has highlighted how changes in external load conditions can influence these characteristics. This has increased our understanding of the eccentric phase and mechanical stimuli afforded by such high-intensity actions.

**Practical Applications**

Overall, supramaximally loaded eccentric-only exercise seems to offer a unique and potent stimulus; individuals can be exposed to extended TUT at high levels of force that exceed what more traditional regimens might offer. When implementing supramaximal loaded, eccentric-only repetitions, practitioners should be mindful to prescribe a load that is well tolerated in the restricted portion (end ROM) of the exercise movement to facilitate continued force production and maintenance of muscular tension for sustained and consistent movement. This study has addressed the acute mechanical response to supramaximally loaded eccentric-only exercise under different magnitudes of external load. Because the experimental approach was devised with practical application in mind, the results provide strength coaches and applied practitioners with a greater understanding of the mechanical demand imposed by supramaximally loaded eccentric-only leg press exercise. Importantly, these data provide new insight into the performance response from strength-trained individuals throughout supramaximal eccentric leg press exercise.

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